

# **Merrimack Village Dam Final Report: Phase I- Dam Removal Feasibility Study VOLUME 1: Main Report**



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**December 2004**

## Acronyms

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acre-ft	acre-foot
APE	Area of Potential Effect
ASTM	American Society for Testing and Materials
BDL	Below Detection Limit
BSAF	Biota-Sediment Accumulation Factors
CB	Consensus-based
cfs	cubic feet per second
cfsm	cubic feet per second per square mile of drainage area
COC	Contaminant of Concern
Corps	United States Army Corps of Engineers
CRREL	Cold Regions Research and Engineering Laboratory
EA	Environmental Assessment
EB	Einstein-Brown
ft	feet
ft <sup>2</sup>	square feet
DHR	Division of Historic Resources
FEMA	Federal Emergency Management Agency
FERC	Federal Energy Regulatory Commission
FIS	Flood Insurance Study
GIS	Geographic Information System
GS	Gomez and Sullivan Engineers
HEC	Hydraulic Engineering Center
HEC-RAS	Hydraulic Engineering Center – River Analysis System
HQ	Hazard Quotient
kV	kilovolt
LOD	Letter of Deficiency
LOMA	Letter of Map Amendment
MCC	Merrimack Conservation Commission
MCDD	Merrimack Community Development Department
mi <sup>2</sup>	square miles
mm	millimeter
MPB	Merrimack Planning Board
MPM	Meyer-Peter-Muller
MVD	Merrimack Village Dam
MW	megawatt
MWH	megawatt-hours
NG	No Guideline
NGVD	National Geodetic Vertical Datum
NHDES	New Hampshire Department of Environmental Services
NHFG	New Hampshire Fish and Game
NHNHB	New Hampshire National Heritage Bureau
NOAA	National Oceanic and Atmospheric Administration
ORNL	Oak Ridge National Laboratory
PAH	Polycyclic Aromatic Hydrocarbon
PCBs	Polychlorinated bi-phenyls
PBTs	Persistent, Bioaccumulative, and Toxic pollutants
PEC	Probable Effect Concentration (McDonald, et al. 2000)

## Acronyms (continued)

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ppb	parts per billion
ppm	parts per million
PWW	Pennichuck Water Works
SQuiRT	Screening Quick Reference Table
SVOC	Semi-Volatile Organic Compound
TEC	Threshold Effect Concentration (McDonald, et al. 2000 and ORNL 1997)
TEL	Threshold Effects Level (NOAA 1999)
TOC	Total Organic Carbon
USEPA	United States Environmental Protection Agency
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
VOC	Volatile Organic Compound

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## 1.0 Introduction/Background

### 1.1 Overview

The Merrimack Village Dam (MVD), located in Merrimack, NH, is the first dam on the Souhegan River, a tributary to the Merrimack River as shown in Figure 1.1-1. The dam is owned by Pennichuck Water Works (PWW), a public water supplier in Merrimack, NH. PWW purchased the dam in November 1964 to serve as a supplementary water storage site, but the dam and impoundment were never used for that purpose. The company is now interested in either removing the dam or transferring its ownership to another entity, which will then be responsible for dam maintenance, operation and any future fish passage requirements.

The topic of removing the MVD was discussed at various Merrimack town meetings. The first mention of potential removal was in an August 2000 letter from the New Hampshire Department of Environmental Resources (NHDES) Dam Bureau to PWW. This letter summarized a site inspection conducted by the Dam Bureau and the topic of dam removal was mentioned. Few discussions were held in the interim period until the Merrimack Board of Selectman discussed the MVD and its potential removal in May 2003.

On June 19, 2003, the Merrimack Board of Selectman held a public hearing to solicit input on the potential removal of the MVD. Presentations were made on the history and current ownership of the dam, dam removal, diadromous<sup>1</sup> fish restoration efforts, and the impact removal could have on sediment, fisheries, and aesthetics. Following the presentation, a question-and-answer session was held. Many of the citizens taking the opportunity to comment supported retaining the dam due to its highly visible location, aesthetic, historic and sentimental value. Many questions could not be answered since further study of the project was needed to provide an educated response. In response to the meeting, the Board of Selectman designated a subcommittee consisting of a member of the Merrimack Planning Board (MPB), and the Merrimack Conservation Commission (MCC) to pursue issues related to dam removal and river restoration.

Following the June 19 meeting, a study plan was jointly developed to identify studies needed to evaluate the impacts dam removal could have on infrastructure, sediment, pollutants (if any), fisheries, wetlands, and property. The study plan was developed in consultation with the NHDES, MPB, MCC, Merrimack Community Development Department (MCDD) and PWW. The studies and background research were designed to answer many of the questions raised at the June 19 meeting and to generally understand the impacts of removal. This report is considered a Phase I feasibility study that investigates the impacts of removing the MVD. A Phase II study may be conducted, depending on the outcome of this study, need for additional information, and feedback from various interested parties.

It should be noted that in January 2004, the NH Dam Safety Department issued PWW a Letter of Deficiency (LOD), meaning that the MVD does not meet certain dam safety criterion. Dam repair and other issues were identified by NH Dam Safety as issues that must be addressed. A combination of the LOD, the fact that PWW does not utilize the dam for water supply, and the long-term liability and maintenance cost associated with the MVD prompted PWW to consider dam removal.

For purposes of this study, only removal of the dam spillway and apron were considered. Other appurtenant facilities, such as the power canal, dam abutments, gates, and training walls extending under

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<sup>1</sup> Diadromous fish include anadromous and catadromous. Anadromous fish migrate from the sea to freshwater to spawn. Catadromous fish migrate from freshwater to the sea to spawn.

Chamberlain Bridge are not being considered for removal. It is not the purpose of this study to evaluate the costs associated with dam repair to resolve issues raised in the LOD.

## 1.2 Study Purpose

This Phase I feasibility study provides information to a variety of interested parties. The town of Merrimack has requested additional data collection and evaluation for the town to make an informed decision on whether to support removal or to potentially take ownership of the privately held dam. For PWV, if the town or another party is not interested in pursuing ownership of the dam, they may pursue full dam removal to reduce their liability and operation/maintenance costs associated with the dam. The feasibility study also provides information to the public on the impacts of removal and the opportunities associated with river restoration through dam removal.

## 1.3 Project Partners

Project Partners who actively participated in this Phase I feasibility study include the NHDES, MPB, MCC, MCDD, PWV, American Rivers and the National Oceanic and Atmospheric Administration (NOAA). This study was partially funded by the American Rivers/NOAA Community-Based Restoration Program Partnership. The mission of American Rivers/NOAA grants is to restore rivers to their natural state and function, including the removal of obsolete dams. The grant program is administered by American Rivers, headquartered in Washington, DC. The feasibility study was performed by Gomez and Sullivan Engineers, P.C. in Weare, NH in coordination with the University of New Hampshire in Durham, NH.

## 1.4 Report Format

This report consists of two volumes. Volume I contains text and some smaller tables. Volume II contains all of the figures, some tables and the appendices.

## 2.0 History

### 2.1 Overview

Over three hundred years ago a band of Penacook Indians settled on the banks of a river they named “Souhegan” roughly translated as “river of the plains”. The Souhegan tribe hunted and fished the river, their trail followed the river through present day Milford, Wilton and Greenville. A 1652 scouting report indicated there were about 50 Indian families near the mouth of Salmon Brook, Nashua River and many more along the banks of the Souhegan and Merrimack Rivers.

The year 1725 marked a turning point for the settlement of the region with the ending of the Captain John Lovewell’s War. As a result of the defeat of the Souhegan and Naticook tribes and the retreat of most of the Indians, more rapid settlement and agrarian development ensued. Early settlers cleared the land and established sawmills to transform the felled logs into material for houses and barns. Each of the communities had its own early saw and grist mills on the Souhegan River.

Early settlements by Europeans were promoted by an abundance of physical features and attractions including meadow land, uplands ready for cultivation, fishing and trapping potential. The fur trade in particular was a significant catalyst in opening new lands to settlement. As beaver were successively trapped out of areas near the frontier trading posts, Indians began exploiting these resources in new regions that were increasingly remote from the European settlements.

In Merrimack the first four known settlers arrived in 1722. Their settlement was known as Souhegannock, later Souhegan. There were three early mills in town including that of Daniel Stearns (later Fullers Mills). Simeon Cummings owned a mill at Atherton Falls while John Chamberlain owned a mill at Souhegan Falls near the present-day fire station. John Chamberlain was given three hundred acres of land to establish a saw mill and grist mill in Merrimack by the Brenton proprietors. He came here sometime prior to 1734 and built a mill at Souhegan Falls in 1744, where Route 3 crosses the Souhegan River today. Early on this village became known as Souhegan Village, later called Merrimack. In 1735, 120 acres were granted to Joseph Blanchard to erect a sawmill and corn mill on the Souhegan River. Other mills were built along Baboosic Brook and Pennichuck Brook.

In the 1890s, Gordon Woodbury of Bedford erected a large shoe factory on the banks of the Souhegan River in Merrimack. In 1906 shoe manufactures W.H McElwain Co. purchased the large plant and water privilege at Souhegan Falls with the intention of enlarging the dam to generate hydroelectric power. Although W.H. McElwain died before this was accomplished, the company carried on the manufacture of sole leather and leatherboard until 1921. In 1921, the International Shoe Co. purchased the McElwain property and operated the factory as a tannery. It was later occupied by the Gate City Poultry Company, New England Chemical and Harcross.

### 2.2 Chamberlain Bridge/Merrimack Village Dam

#### 2.2.1 Chamberlain Bridge

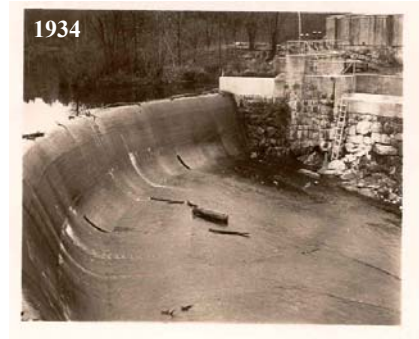


The present day Chamberlain Bridge was constructed in 1921 by the Lovejoy Granite Company of Milford. It is one of the only surviving granite bridges that is straight on one side and curved on the opposite side. The original bridge, built in 1806, was wooden. The granite bridge has a main arch with a 60’2” clear span and a smaller arch that carries a power canal through one spandrel to a former mill on the downstream side. The Merrimack Village Dam (MVD) is located immediately

upstream of the bridge. The bridge was widened on the downstream side in 1934 using curved reinforced concrete, faced with stone to form the original fascia. On July 28, 2003, the State of New Hampshire placed Chamberlain Bridge on the State Register of Historic Places.

### 2.2.2 Merrimack Village Dam

The original dam structure was a gravity stone masonry dam constructed on bedrock outcroppings. According to the NHDES Dam Bureau files the original structure dates to at least 1907<sup>2</sup>. In 1916 the height of the dam was increased, and circa 1934 the spillway was capped with concrete to form the current arched ogee spillway and concrete apron. Evidence of former flashboards can be detected by the existing steel sleeves located every six feet on center across the spillway. Based on the construction dates of the Chamberlain Bridge and the MVD it appears that the dam was constructed before the present day Chamberlain Bridge. This may explain why the smaller arch of Chamberlain Bridge conveniently spans the power canal.



Handwritten correspondence in the NHDES files indicated that the ogee spillway was constructed over the masonry dam to prevent spray from hitting the Chamberlain Bridge and affecting the Route 3 road crossing. The former purpose of the 1934 dam was to generate electricity for leather manufacturing at the International Shoe Company. The most recent purpose of the dam was to provide water to the New England Chemical Company that formerly operated a chemical storage, manufacturing and distribution business in buildings located downstream of the dam (the mill buildings have since been removed). The dam was purchased by PWW in the November 1964 to provide a supplementary water supply, although it was never used.

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<sup>2</sup> The date of 1907 was detected on the gate structure (Ref: Army Corps of Engineers, Phase I Inspection Report, Feb 1979).

### 3.0 Souhegan River Watershed and Hydrology

#### 3.1 Watershed Description

The Souhegan River originates in the town of Ashburnham, MA and flows in a northeasterly direction approximately 17 miles until it turns easterly in the town of Wilton before flowing another approximate 17 miles to the Merrimack River as shown in Figure 3.1-1. The south and west branches of the Souhegan Rivers join together in New Ipswich, forming its headwaters. The approximate 34-mile river flows through the communities of New Ipswich, Greenville, Wilton, Milford, Amherst and Merrimack before discharging into the Merrimack River. The drainage area of the basin is approximately 220 square miles ( $\text{mi}^2$ ). Shown in Figure 3.1-2 is a land use map depicting the forested, wetlands, developed, and other land uses within the watershed. As the map shows, the upper portions of the watershed in New Ipswich, Greenville and Wilton are relatively undeveloped and have considerable wetland areas. Urbanization increases through the communities of Milford, Amherst and Merrimack where business centers are located.

Bedrock in the basin consists of hard crystalline Paleozoic rock. Soils are composed of variable, unstratified, silty, gravelly sand and clays with interspersed cobbles and boulders. General soil conditions are acidic, stony and thin to bedrock. The geology of the Souhegan River corridor provides many of the communities with their only source of public water supplies. The stratified drift aquifers that follow the river corridor provide a source of high quality/high quantity drinking water used for public supplies by the Towns of Merrimack, Milford and Wilton.

The topography of the watershed varies considerably from flat floodplains in the eastern portion to rolling hills and steep slopes in the west. Watershed elevations range from a high of 2,280 feet at the summit of Pack Monadnock in Peterborough and 2,276 feet at the summit of North Pack Monadnock in Greenfield to roughly 100 feet at the confluence of the Souhegan and Merrimack Rivers in Merrimack. In its 34 miles, the river drops approximately 850 feet from New Ipswich (950 feet) to Merrimack (100 feet) an average drop of 25 feet per mile. Major drops in river gradient are concentrated in rapids within Greenville, Wilton and Merrimack. For example, Wildcat Falls, located approximately 0.8 miles upstream of the MVD results in a drop of approximately 83 feet over a series of three falls (Ref: Souhegan Watershed Study, 1995).

Because of the river's high gradient numerous dams were constructed along the Souhegan River mainstem as shown in Figure 3.1-3. The majority of dams are concentrated in the upper portions of the basin, where the river gradient was harnessed to power various historic mills. Many of the dams that were once an integral component of the industrial revolution are now abandoned. In addition to the mainstem dams, there are numerous other dams located on tributaries including 12 state-operated flood control facilities designed to reduce and attenuate floods. The flood control facilities came on-line in the late 1960s and early 1970s to reduce peak flows in the Souhegan River.

The MVD is located approximately 1700 feet upstream of the confluence with the Merrimack River. The drainage area of the MVD is  $171 \text{ mi}^2$ , as computed from a Geographic Information System (GIS) overlay of the Souhegan River Basin. The next upstream dam, McClane Dam in Milford, has a drainage area of approximately  $138 \text{ mi}^2$ . Removal of the MVD would result in just over 14 miles of free-flowing mainstem river and provide fish with access to numerous intervening tributaries (although many of these tributaries have dams as well).

It should be noted that the Souhegan River is one of 14 rivers designated by the NHDES to establish long-term instream flows for protection of fish, wetlands, wildlife, recreation and a host of other resources.

There is currently an instream flow evaluation being conducted on the Souhegan River to establish future protected instream flows.

### 3.2 Hydrology

The evaluation of dam removal projects, including fish passage that may be restored after removal and sediment management, requires an understanding of the magnitude, timing and duration of a river's flow. Hydrologic (or flow) data is a key component to any dam removal study. High flow data is commonly needed to evaluate sediment transport within the impoundment and scour of infrastructure. For example, the MVD impoundment is filled with sediment and removal could transport this material under a high flow event, unless dredging is conducted or the material is stabilized in-place. Low flow information is equally important as the dewatered impoundment or "newly" formed river channel must provide sufficient depths and velocities for fish to move freely upstream and downstream after dam removal.

#### 3.2.1 General

The MVD is located just downstream of a United States Geological Survey (USGS) gage in Merrimack, referred to as the Souhegan River at Merrimack gage (Gage No. 01094000) as shown in Figure 1.1-1. The drainage area at the gage is published as 171 mi<sup>2</sup>, the same as MVD. The USGS gage has been sporadically active. Continuous periods of flow data are available from July 13, 1909 to September 30, 1976 and October 1, 2001 to current. The USGS also reports the real-time flow at the gage in 15 minute increments, which can be accessed from the USGS' website<sup>3</sup>.

Using the available period of record various flow statistics were developed to understand the timing, magnitude and duration of streamflow at the MVD. Shown in Figure 3.2.1-1 and Table 3.2.1-1 are the mean and median monthly flows at the gage for the period of record. The mean and median annual flow at the MVD is 283 cfs (1.66 cfs per square mile of drainage area or cfs/m) and 150 cfs (0.88 cfs/m), respectively.

**Table 3.2.1-1 Mean and Median Monthly Flows at Merrimack Village Dam, Period of Record: 1909-1976, 2001-2003 (Units: cfs and cfs/m), Drainage Area= 171 mi<sup>2</sup>**

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
<i>Mean</i>												
cfs	267	270	627	770	381	215	100	78	88	106	223	283
cfs/m	1.56	1.58	3.67	4.50	2.23	1.26	0.58	0.46	0.51	0.62	1.30	1.65
<i>Median</i>												
cfs	182	189.5	435	591.5	290	128	56.5	41	40	49	125	180
cfs/m	1.06	1.11	2.54	3.46	1.70	0.75	0.33	0.24	0.23	0.29	0.73	1.05

To understand the distribution of flows in a given month and throughout the year, flow duration curves were developed on a monthly and annual basis. A flow duration curve displays the relationship between flow and the percent of time a given flow is equaled or exceeded. Shown in Figures 3.2.1-2 through 3.2.1-5 are monthly flow duration curves for January through December (three months per figure). Shown in Figure 3.2.1-6 is the annual flow duration curve. For example, in reviewing the August flow duration curve the 50% exceedence flow (also called the median flow) is 41 cfs (0.24 cfs/m), thus on an average 50% of the flows are greater than 41 cfs during August.

<sup>3</sup> Website: [http://nwis.waterdata.usgs.gov/nh/nwis/uv/?site\\_no=01094000&agency\\_cd=USGS](http://nwis.waterdata.usgs.gov/nh/nwis/uv/?site_no=01094000&agency_cd=USGS)

The 7Q10 flow, the lowest seven day sustained flow which occurs once in ten years, for the Souhegan River is 12.8 cfs (Ref: Souhegan River Watershed Study, 1995).

The range of flows experienced at the MVD will be used in the hydraulic model to predict water depths, and velocities near the dam (post removal) and throughout the impoundment.

### 3.2.2 Floods

The Federal Emergency Management Agency (FEMA) conducted a flood insurance study (FIS) of the Souhegan River through the town of Merrimack. The study was conducted in 1979 and was based on the MVD being in-place. The FIS provides information on the expected area of inundation due to flood flows of varying return intervals such as the 10-, 50- and 100-year flood flow. For example, the 100-year flood flow is expected to occur once every 100 years.

If the MVD is removed, it will lower the floodway (the width of the river under flood conditions) as currently estimated in the FIS. When a change in the floodway occurs, FEMA typically requires a Letter of Map Amendment, commonly called a LOMA. As described later, a hydraulic model of the Souhegan River, based on the same FIS, was used to estimate water elevations under certain flood events. The estimated floodway, with the MVD removed, was predicted with the hydraulic model.

The purpose of the flood insurance program is to investigate the existence and severity of flood hazards in the Town of Merrimack. In the late 1970s, detailed flood insurance studies were conducted on numerous rivers in Merrimack, including the Souhegan River. As part of these studies a hydraulic model of the Souhegan River was developed. A hydraulic model predicts the water depth (or elevation) and velocity at various locations in the river under different flood flows. Flood flows were estimated under return intervals of 10-, 50-, 100- and 500-years.

According to the 1979 study, the principal sources of estimating flood flows on the Souhegan River in Merrimack were discharges published by the United States Army Corps of Engineers (Corps) and the Soil Conservation Service. The FIS reported the following flood flows as shown in Table 3.2.2-1.

**Table 3.2.2-1: Flood Insurance Study, Flood Flows for various Return Intervals on the Souhegan River upstream of the confluence with Baboosic Brook.**

Location	Drainage Area	10-year	50-year	100-year	500-year
Souhegan River upstream of the confluence with Baboosic Brook	171.5 sq mi	6,920 cfs	11,900 cfs	12,500 cfs	22,000 cfs
Estimated Souhegan River flow at MVD*	171.0 sq mi	6,900 cfs	11,870 cfs	12,460 cfs	21,940 cfs

\*Estimated by drainage area proration. For example, the 10-year flood:  $\frac{171}{171.5} \times 6920 \text{ cfs}$

The flood flow data in the above table was used with the hydraulic model to predict sediment transport.

It should be noted that there are various methods to compute flood frequency statistics similar to those shown in Table 3.2.2-1, which may yield slightly different results. We relied on the flood insurance study, however, the NHDES used a report entitled “*Hydrologic Data for Gaged Watersheds of New Hampshire and Vermont*” to estimate flood flows at the MVD. NHDES used the flood flow data to determine if the MVD could safely pass the 50-year flood flow. Based on this report, the 50-year and 100-year flood frequencies were computed as 10,870 cfs and 13,330 cfs, respectively. For purposes of this report and for consistency with the FEMA study, we used the values in Table 3.2.2-1, which are slightly higher than values used by NHDES.

## 4.0 Merrimack Village Dam and Impoundment

### 4.1 Merrimack Village Dam- Physical Description

The current MVD is a 20-foot high arched concrete structure with a 145-foot long ogee-shaped spillway—the total length of the structure including abutments is approximately 180 feet. Shown in Appendix A<sup>4</sup> are historic and current pictures of the MVD as well as pictures from above and below the dam. Besides the fixed spillway, the dam has two low-level outlets that lead into a power canal passing beneath the Route 3/Chamberlain Bridge. A 2-foot x 2-foot low-level sluice gate was installed in 1990 alongside a 6-foot wide by 7.5-foot deep stop log bay. Past surveys and drawings of the dam were conducted by the Corps of Engineers, as part of their Phase I Inspection.

The 1934 improvements to the MVD—from a broad-crested to an ogee-shaped spillway—included a concrete apron to reduce spray that presumably was causing ice formation on the Route 3 Bridge. The apron extends approximately 120 feet downstream from the toe of the spillway to its end beneath the Chamberlain Bridge. At the toe of the spillway, the apron thickness is at least 1.5 feet according to the 1934 NH Highway Department drawings. At the aprons end, the measured thickness is approximately 4 inches. Approximately 20 feet of natural channel under the Chamberlain/Route 3 Bridge is covered by the apron, and along the right bridge abutment the apron reaches to within 10 feet of the northeast face of the Chamberlain Bridge. It is unknown at this juncture if the apron is reinforced, which can play a role in removal costs. A reinforced structure or apron typically require more time to remove.

Shown in Figure 4.1-1 is a plan view of the MVD, canal structure, and Chamberlain/Route 3 Bridge. Figures 4.1-2 through 4.1-5 detail the dam cross-section and the canal structure. Shown in Figure 4.1-2 is a scanned cross-section of the former (prior to 1934) dam and proposed (now existing) dam. This figure is a 1934 Highway Department drawing of the original dam crest and the ogee crest currently in place. It should be noted that a complete survey of the dam and canal structures was not conducted. Instead, existing plans from the Army Corps of Engineers and previous Federal Energy Regulatory Commission (FERC) licensing applications were obtained and key elevations were confirmed in the field as part of this study.

The MVD is classified by the NHDES Dam Bureau as a Class A “Low Hazard” dam. According to Env-Wr 101.04 failure of a Class A dam would result in any of the following: a) no possible loss of life, b) minimal economic loss, c) major damage to town and city roads; or d) minor damage to Class I and II state highways.



### 4.2 Merrimack Village Dam- Deficiencies

The most recent inspection of the MVD was conducted by NHDES Dam Safety engineers on October 21, 2003. On January 14, 2004, NHDES issued a Letter of Deficiency (LOD) to PWW requiring that they correct the following deficiencies (the full letter is in Appendix B):

1. Prepare and submit to the NHDES a written operations and maintenance procedure plan.
2. Provide NHDES with a plan for increasing the discharge capacity of the dam or show that the dam is stable from overtopping. The NHDES concluded that the dam cannot pass the 50-year storm event (this was based on a 50-yr flood flow of 10,870 cfs) without overtopping the dam abutments.

<sup>4</sup> Appendix A contains numerous pictures of the project from various site visits.

3. Removal of the sediment that has developed in front of (i.e., the upstream side) of the gate structure, which prevents operation of both the sluice and stoplog bay.
4. Remove the vegetation from the discharge channel downstream of the gate and stoplog bay.
5. Remove trees and shrubs growing within 10 feet of the abutment walls and from within 10 feet of the gate and stoplog bay section.
6. Repair deteriorated concrete in the following areas a) on the upstream lip of the spillway at the interface between the left<sup>5</sup> abutment wall and spillway, b) on sections of the spillway downstream face at the far right end of the dam.
7. Repair missing and loose stonework and related deterioration of the interior face of the left spillway training wall.
8. Monitor the area of leakage that was noted along the downstream left spillway training wall.

On February 2, 2004, PWW requested a two-year extension of the compliance schedule while the Phase I Dam Removal Feasibility Study is conducted. NHDES followed up with PWW stating that numbers 1, 4, and 5 (as listed above) must be completed by June 1, 2004. NHDES granted the two-year extension on the remaining items, with the understanding that this feasibility study will be undertaken.

It is not in the scope of this study to evaluate the cost associated with addressing and correcting items 1-8 above, however, if another party is interested in purchasing the dam an assessment is highly recommended.

In reviewing past correspondence, and having conducted numerous site inspections, one of the major issues confronting the MVD is the continual sediment build-up behind the dam and gate structure. The sediment build-up behind the gate structure prevents operation of both the sluice gate and stoplog bay. It is also evident that sediment has deposited in the power canal, rendering the canal unusable. According to a member of the Fire Department (located on river left next to the dam), the gate was not sealed near the bottom, allowing fine sediment to move through the gate structure and build-up in the power canal. Water and fine sediment were observed passing beneath the bottom of the gate due to the pressure head differential. A portion of the sediment in the canal may be the result of flow and suspended sediment overtopping the stoplog bay under high flow conditions. Removal of the sediment in front of the gates will be necessary whether the dam remains or is removed. If dam removal occurs the gates must be operable to drain the impoundment for removal equipment to access the dam. If the dam remains, the gates would assist in passing flood flows.

#### 4.3 Merrimack Village Dam Impoundment

The impoundment created by the MVD extends upstream approximately 1,650 feet to just below the Everett Turnpike Bridge. Removal of the dam would convert some of the impoundment back to a riverine environment after sediment transport and/or sediment removal is conducted. Well upstream of the Everett Turnpike Bridge, the Souhegan River water depths, velocities and flows are not affected by the MVD. Shown in Appendix A (see Photos 24 & 25) are photographs of the Souhegan River from the Everett Turnpike Bridge showing the separation between free-flowing water beneath the bridge and the impoundment created by the MVD.

A bathymetric<sup>6</sup> map (see Figure 4.3-1, Existing Conditions Map) of the impoundment was created to estimate the volume and surface area of impounded water. To develop the bathymetric map on May 13,

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<sup>5</sup> In this document we refer to the left or right side of the dam. The left side of the dam assumes one is looking downstream- conventionally called "river left". Likewise, "river right" is the right side of the dam (or river) looking downstream.

14 and 17 a survey crew equipped with a boat, depth finder and GPS obtained depth measurements throughout the impoundment. The water surface elevation in the impoundment was surveyed at the start and end of each day. An existing benchmark<sup>7</sup> located atop Chamberlain Bridge was used as a reference.

Shown in Figure 4.3-1 is the existing conditions plan, including the bathymetric map, of the impoundment. The estimated volume of the impounded water (at water level 122.8 feet) is 21.3 acre-feet and the estimated surface area<sup>8</sup> is approximately 10.9 acres at elevation 122.8 feet. Over time, the impoundment has become filled with sediment resulting in a reduction of the storage volume created by the dam.

As seen from the bathymetric map, steep contours are shown along the right bank of the impoundment—it is suspected that this is the location of the former river channel. The left channel is relatively shallow, providing much less conveyance than the right channel. A large island/bar formation fills the middle of the impoundment with coarse sand. The upland areas above the right and left banks are covered in trees with sparse undergrowth.

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<sup>6</sup> A bathymetric map is the same as a topographic map, but it represents the underwater contour lines of the impoundment.

<sup>7</sup> The benchmark is located in Merrimack – A standard NGS&SS disk set in the top of the north-east parapet wall of Route 3/Chamberlain Bridge over the Souhegan River. RM 26, Elevation 133.45 feet, NGVD 1929.

<sup>8</sup> The surface area was computed from the bathymetric map and includes the islands within the impoundment as well as the wetland behind the fire department.

## 5.0 Sediment Sampling, Testing and Management

### 5.1 Estimated Volume of Sediment

To estimate the volume of sediment impounded by MVD sediment depth measurements were obtained at seven transects along the Souhegan River as shown in Figure 4.3-1. A measuring tape was extended across each transect and the depth of water and depth of sediment were measured. At each transect the water surface elevation was surveyed (at approximately 70 cfs on June 29 and 78 cfs on June 30), thus all transect plots are referenced on a common vertical datum. The depth of sediment was obtained approximately every 10 feet at narrow transects and 20 feet at wider transects by hammering a pre-marked steel rod to the point of refusal. The purpose for obtaining the sediment depth measurements was two fold. First, by hammering to refusal the former river morphology in the impoundment could be estimated absent the sediment. Second, the approximate sediment volume within the impoundment was calculated.

Shown in Figures 5.1-1 through 5.1-7 are the transect plots showing the water surface elevation, the present river cross-section and the river cross-section showing the depth of sediment for transects T-1 through T-7, respectively. Note that transect T-1 is located at the outlet of wetland behind the fire department.

A few notes are worth mentioning with respect to the depth of sediment. A sledge hammer and a rigid steel rod were used to penetrate the sediment to the point of refusal. We speculate that the point of refusal is where the former river channel was located; however, it should be clearly noted this is not a precise measurement. Parties should keep this in mind when reviewing the findings.

The volume of sediment was computed by multiplying the average of bounding sediment depth measurements by the station width, and then summing the polygons across each transect—this yields the cross-sectional area of sediment and/or water for each transect. A function of the transect sediment area in conjunction with transect areas taken immediately upstream and downstream was then multiplied by half the distance between consecutive transects to compute a volume. This function accounts for transitions in channel bed elevations between consecutive cross-sections. The calculated volume of sediment between the MVD and the upstream extents of the impoundment is approximately 81,000 yd<sup>3</sup> or 50.2 acre-feet. Currently, there are 21.2 acre-feet of impounded water, accounting for less than one-third of the total impoundment volume. It should be noted, however, that sediment pockets exist in free-flowing streams, where river velocities slow and sediment is deposited. Essentially, not all of the sediment volume measured will be mobilized if the dam is removed, as there appears to be a natural ledge upon which the dam is founded. More discussion on sediment removal and management is provided later in this report

In addition to the sediment depth measurements along transects within the impoundment, steel rods were also driven to refusal at several locations immediately behind the MVD. Shown in Figure 5.1-8 are the sample locations enumerated with a number. The number reflects the depth to refusal relative to the water surface elevation. The purpose of these depth measurements was to have a sense of the channel morphology immediately behind the dam for use in simulating dam-out conditions within the hydraulic model as described later. Shown in Figure 5.1-9 is a composite<sup>9</sup> transect representing the depth of water and sediment immediately behind MVD.

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<sup>9</sup> The composite transect reflects the depth of sediment and water based on a curved transect (same curvature as the dam), immediately behind the dam.

## 5.2 Sediment Sampling Protocol

Sediment and associated pollutants that are carried by rivers generally settle directly behind dams where water velocities slow. Of concern with any dam removal project is the potentially harmful release of these accumulated sediments and pollutants to the downstream river channel and aquatic environment. Before dam removal occurs, it is common to conduct sediment testing to determine sediment size via a grain-size analysis (to determine the potential for sediment mobility) as well as to test for pollutants.

The NHDES has established protocols for sampling sediments before dam removals occur. The NHDES protocol (Evaluation of Sediment Quality for Dam Removals) requires four (4) samples be taken from the channel bed to the point of refusal. Target areas should be subject to deposition of fine particles. Suggested locations are:

- One (1) upstream of the extents of the impoundment
- One (1) in the impoundment
- One (1) in the impoundment, adjacent to the dam
- One (1) downstream of the dam

Sediment samples must be collected in accordance with the U.S. Environmental Protection Agency's (USEPA) Methods for Collection, Storage and Manipulation of Sediments for Chemical and Toxicological Analyses: Technical Manual (EPA-823-B-01-002, 2001) and the NHDES Department Policy on Evaluation of Sediment Quality (NHDES-R-WD-04-9). Sediment samples must be examined for both physical properties and chemical constituents. The tests required by the protocols include:

- Grain-size Analysis by ASTM D-422
- Total Organic Carbon (TOC)
- Polynuclear Aromatic Hydrocarbons (PAHs) by USEPA 8270C
- Polychlorinated bi-phenyls (PCBs) by USEPA 8082
- Pesticides by USEPA 8081
- Volatile Organic Compounds (VOCs) by USEPA 8260B
- Semi-volatile Organic Compounds (SVOCs) by USEPA 8270C
- Metals (Arsenic, Barium, Cadmium, Chromium (total), Copper, Lead, Mercury, Nickel, and Zinc) by USEPA 6010 and 7174 (for mercury)

Protocols suggest that pollutant concentrations be compared to various sediment quality criteria in order to determine if any contaminants exist at elevated levels or if any contaminants pose a risk. The suggested screening criteria include Threshold Effect Concentration (TEC) and Probable Effect Concentration (PEC) values listed in MacDonald *et al.*, 2000, NOAA 1999 SQUIRT Tables, Oak Ridge National Laboratory 1997 Toxicological Benchmarks (ORNL ES/ER/TM-95/R4), and/or USEPA 1996 Ecotox Thresholds (EPA 540/F-95/038).

## 5.3 Sediment Testing Sampling Results

### 5.3.1 United States Fish and Wildlife Service Sediment Sampling

In 2003, the United States Fish and Wildlife Service (USFWS) collected five (MVD-01, MVD-02...MVD-05) sediment samples in the MVD Impoundment as shown in Figure 5.3.1-1. The depth of

penetration for each sample was less than 0.5 meters (less than 1.6 feet). The USFWS attempted to collect the samples using an Ekman and KB corer, but were unsuccessful due to the compacted nature of the sediment. Because the sediment was difficult to penetrate, the USFWS used a stainless steel ponar, or when that was not successful, stainless steel trowels were used to obtain the sediment sample. All sampling gear was decontaminated between each sampling.

The sediment samples taken in 2003 by the USFWS were collected for screening purposes and to determine if additional sampling was warranted. The USFWS sampling was completed before this more in-depth feasibility study was initiated. Although NHDES has developed sediment sampling protocols for dam removal projects, the USFWS screening study did not sample below the dam and did not include VOC and SVOC sampling. All other testing was the same as the NHDES protocols. After June 2004, NHDES requested that an additional sediment sample be collected in the canal given that this sediment may need to be removed whether the dam remains or is removed.

Results from the sediment contaminant analysis were compared to the suggested screening criteria values. As shown in Table 5.3.1-1, the screening criteria used in order of precedence were the consensus-based Threshold Effect Concentration (TEC) and Probable Effect Concentration (PEC) values listed in MacDonald *et al.*, 2000, Threshold Effects Level (TEL) from NOAA Screening Quick Reference Tables (SQiRTs), and the TEC values from Oak Ridge National Laboratory 1997 – Toxicological Benchmarks. The NOAA screening criteria are generally the most stringent. Values shown in bold exceed the consensus-based TEC values, as this set of criteria were deemed appropriate for use by NHDES after their initial review of the results. A full set of analytical results and a quality control report for the USFWS samples is located in Appendix C.

Note that samples from Site MVD-05 were collected from an area at the head of the impoundment, approximately 300 feet downstream of the Everett Turnpike Bridge. During the field visits, this site appeared inundated by backwater effects of the impoundment. However, there was very little sediment accumulation across the river in this location; most of the substrate was large cobble and boulder. There were isolated pockets of fine-grained sediment, particularly behind larger boulders along the shallower areas near to the shore. All of the exceedences of the sediment screening criteria listed in Table 5.3.1-1 were highest at the upstream site (MVD-05) and mostly related to PAH's. This is probably associated with its relative location to the Everett Turnpike Bridge.

The only Persistent, Bioaccumulative, and Toxic pollutant (PBT) found in the sediment above the screening criteria was benzo(a)pyrene, which exceeded the TEC criteria at site MVD-05.

Based upon these results, the most impacted site is the upstream site - MVD-05. In addition to our analysis, the USFWS will conduct their own analysis, which was not available at the time of this report.

### 5.3.2 Additional Sediment Sampling

Based upon review of the results from the USFWS, additional sediment sampling was recommended by NHDES in accordance with their analysis protocol. Recommended follow-up sampling was two-fold. First, a sediment sample was collected from the canal for chemical and physical analysis (MVD-06). Second, sediment was collected from two locations for toxicity testing: 1) MVD-05, which was upstream and had the most concentrated contaminants in the sediment-particularly PAHs, and 2) MVD-03, at the downstream side of the islands in the impoundment (see Figure 5.3.1-1). The latter site was selected due to the levels of two PAH compounds – benzo(k)fluoranthene and indeno(1,2,3-cd)pyrene – exceeding the TEC criteria. Recognizing that MVD-02 and MVD-01 had levels of indeno(1,2,3-cd)pyrene in exceedence of the TEC criteria (but lower than levels at MVD-03), toxicity of these compounds can be adequately assessed from the sediment collected at MVD-03.

The toxicity testing entailed collecting sediment from the river and placing organisms in with the sediment under laboratory conditions to determine if any adverse effects are observed. In consultation with NHDES, a 10-day survival and growth test using the freshwater amphipod *Hyalella azteca* was performed using sediment collected from the two sites mentioned above. This testing was conducted in accordance with USEPA protocols.

The collection of additional sediment samples was conducted by Gomez and Sullivan on September 17, 2004. The laboratory analysis for the canal sample was conducted by Eastern Analytical Labs in Concord, NH and included all the parameters required by the NHDES protocol (grain size, TOC, organics and inorganics). EnviroSystems in Hampton, NH conducted the toxicity testing.

The results of the chemical analyses of the sediment collected from the canal site (MVD-06 shown in Figure 5.3.1-1) reveal that all organic parameters were below detection limits. Certain metals were detected, as presented in Table 5.3.2-1, however none of the metals found in the sediment from this location were in excess of the listed sediment screening criteria. A full set of analytical results, detection limits and a quality control report for the sediment samples is located in Appendix C.

**Table 5.3.2-1: Sediment Sampling Results for Merrimack Village Dam, Canal Site (MVD-06)**

Compound	Screening Criteria mg/kg dry weight				Results mg/kg dry weight
	SQuiRT TEL	ORNL TEC	Consensus- based TEC	Consensus- based PEC	MVD-06
Arsenic	5.90	12.1	9.79	33.0	1.1
Barium	NG	NG	NG	NG	13.0
Cadmium	0.596	0.592	0.99	4.98	BDL
Chromium	37.30	56.00	43.4	111.0	2.9
Copper	35.70	28.00	31.6	149.0	1.3
Lead	35.0	34.2	35.8	128.0	3.0
Mercury	0.174	NG	0.18	1.06	BDL
Nickel	18.00	39.6	22.7	48.6	2.0
Zinc	123.1	159.0	121	459	12.0

NG=No Guideline

BDL=Below Detection Limit

NG=No Guideline

BDL=Below Detection Limit

TEL=Threshold Effects Level (NOAA 1999); TEC=Threshold Effect Concentration (Oak Ridge National Laboratory 1997); PEC=Probable Effect Concentration (McDonald, et al. 2000)

It is also important to note that monitoring has been conducted downstream of the MVD due to the presence of an inactive waste site (the former Harcos Chemicals site). Sediment samples associated with the Harcos site were collected on June 17, 2004 by Earth Tech, Inc. as requested by NHDES. The only metal evaluated at this downstream location was chromium, for which the concentration equaled that of MVD-04 (4.3 mg/kg), and was less than the concentration at the other four MVD sampling locations. Similarly, the concentrations of PAHs were equal to or less than those of MVD-04, the MVD location with the least PAH concentrations. Pesticides were not evaluated in the Harcos samples. These comparisons indicate that the contaminant concentrations observed in the upstream and impoundment samples (collected by USFWS) are greater than those naturally occurring.

The results of the 10-day toxicity testing (survival and growth test using the organism *H. azteca*) reveal sediment collected from both sites is considered “negative toxicity” (i.e., an effect of less than 20% on the endpoint). Further, the growth test results indicate that organisms grown in sediment collected from sites

MVD-03 and MVD-05 showed slightly higher growth rates as compared to the control organisms. Table 5.3.2-2 summarizes the results of the toxicity tests. The complete analytical report for the toxicity testing is located in Appendix C.

**Table 5.3.2-2: Merrimack Village Dam Toxicity Testing Results**

Site	Mean Survival Rate per Site	Mean Dry Weight per Site (mg/individual)
MVD-03	86.3 %	0.108
MVD-05	93.8 %	0.089
Lab Control	87.5 %	0.083

Considering that the results of the sediment chemical analysis revealed there were no exceedences of the probable effects concentration values in the USFWS samples and that the toxicity testing confirmed that the sediment did not affect the growth or survival of the aquatic test organisms, it is believed that risk associated with the contaminants found in the sediment is considered low.

A further requirement of the NHDES sediment policy is that “A sediment contaminant with bioaccumulation potential and, if a TEC is available, HQ-TEC>1 mandates the evaluation of actual or predicted tissue concentrations for assessment of adverse impact on relevant organisms. Relevant organisms include those species that use the contaminated site for resting, feeding, rearing, or reproduction.” *Bioaccumulation* is defined as the accumulation of contaminants in the tissue of organisms through any route, including respiration, ingestion, or direct contact with contaminated water, sediment, pore water, or dredged material (USEPA 2000 [EPA-823-R-00-001]). The degree of *bioavailability* of a contaminant under various exposure scenarios determines the potential for bioaccumulation and toxicity (USEPA 2000).

Benzo(a)pyrene, a PBT compound, was detected in the sediment sample at MVD-05 at a concentration higher than the TEC (HQ-TEC=1.41). This compound is a PAH and is generated by various combustion sources and is also a component or contaminant of such materials as tar and asphalt. The suggested information regarding the chemistry and toxicity of benzo(a)pyrene was reviewed and is summarized here.

The theoretical contaminant concentrations in tissue were calculated using the following formula, as recommended by USEPA 2000:

$$BSAF = (C_t/f_1) / C_s/f_{oc}$$

Where BSAF is the Biota-Sediment Accumulation Factor,  $C_t$  is the contaminant concentration in the organism,  $f_1$  is the lipid fraction in tissue,  $C_s$  is the contaminant concentration in sediment (generally dry weight), and  $f_{oc}$  is the organic carbon fraction in sediment.

USEPA has published a Summary of Biological Effects Tissue Concentrations for benzo(a)pyrene, in which numerous toxicology studies are summarized and several BSAFs for benzo(a)pyrene are presented. In applying the formula above, a BSAF value of 0.01 was used, which is the approximate median of values listed for mollusks in the USEPA appendix table. This value can be used to estimate tissue concentrations of relevant organisms that may live in the project impoundment.

The calculation was applied to a theoretical mussel species, using the BSAF of 0.01, a tissue lipid fraction of 0.01, and the measured organic carbon (0.00001) and benzo(a)pyrene (211 µg/g) in the sediment collected from MVD-05. The resulting theoretical contaminant concentration equals approximately 2.1 µg/g.

NHDES guidance suggests comparing predicted tissue contaminant concentrations to published toxicity values for relevant organisms to assess risk. In this summary, biological effects at certain tissue concentrations were presented for several mollusk and fish species. This summary also presents studies on fish which suggest that benzo(a)pyrene is metabolized rapidly during short-term exposure periods and when fish were fed with contaminated feed. These studies were reviewed in order to compare the theoretical tissue contaminant concentrations with published acute and chronic toxicity values for relevant organisms. Using the calculated value of 2.1 µg/g, no studies indicated observable effects on organisms above this level. Bioaccumulation was considered and additional BSAF calculations were performed for other species using realistic assumptions for the key variables. However the fish species listed in the biological effects summary were not considered because it has been demonstrated that fish species metabolize benzo(a)pyrene rapidly.

Bioavailability of sediment contaminants is influenced by a wide range of physical, chemical and biological factors. Several important factors must be considered in order to adequately estimate the potential for bioavailability and subsequently bioaccumulation. First is that the uptake and accumulation of benzo(a)pyrene is related to the amount of total organic carbon (TOC) in the sediment. Given that the TOC levels found in sediment from site MVD-05 were extremely low (reported as <0.000%) indicates that benzo(a)pyrene is not bound to organic matter and therefore, likely more bioavailable for uptake. However, many of the predictive bioaccumulation models that rely on the relationship between sediment–pore water partitioning and TOC assume that the compound is not metabolized (USEPA 2000). Additionally, the studies are done under steady-state conditions. At the MVD-05 site, sediment composition and possibly contaminant concentrations are not in steady-state conditions due to the riverine nature of the sampling location.

In summary, the sediment chemical analysis and subsequent toxicity testing indicates that contaminants are not likely to be readily bioavailable and pose no risk to downstream ecosystems. The potential for bioaccumulation of benzo(a)pyrene is most likely very low due to the relatively small concentration in the sediment in relation to the TEC (HQ-TEC=1.41), the affinity for such compound to be quickly metabolized by fish, and the dynamic nature of the sediment composition at this site. Furthermore, TOC levels are generally inversely related to bioavailability. TOC levels are somewhat higher at the other sites in the impoundment as compared to MVD-05, which would likely result in lower contaminant concentrations in tissue from organisms living in the impoundment. Thus, as described later, preference is given to allow natural transport of sediments within the impoundment.

#### 5.4 Sediment Composition

Qualitative analysis of the impounded sediment was undertaken by GS during a site survey investigating the depth of sediment and presence of bedrock in the impoundment. Depth investigations revealed that the sediment was stratified, with layers of silt/clay separating very loose layers of sand. The stratification is not consistent throughout the impoundment. Stratification was evident in the upper impoundment (above the bar formations or “islands”) to a greater extent than in the lower impoundment (above the MVD and below the bar formations).

The mid-channel and point bar formations in the impoundment consist of sand, ranging from very coarse sand in the upper impoundment to fine sands immediately behind the dam. The sediment is very loose, and easily disturbed. Air is entrained in the sediment pores, and is released when the sediment is disturbed.

The main channel (portion of the impoundment with the greatest conveyance) runs along the river-right bank of the impoundment. The sediment on the channel bottom is non-cohesive silt/clay, and forms a

very soft mud. Portions of the left bank that are not sandy point-bars consist of the same soft clays that form the right bank.

In the impoundment immediately behind the dam, the river-right portion is entirely bedrock with cobbles and gravel. At the wetland outlet (river-left), the impoundment bottom is sandy silt covered by a thick layer of decaying regolith for a total depth of approximately 11+ feet.

Table 5.4-1 shows the grain size analysis and total organic carbon content of the samples collected by USFWS. The sediment is largely composed of sand with very little organic material. The most upstream site (MVD-05) contained more silt and clay than the sample sites within the impoundment.

**Table 5.4-1: Sediment Grain Size Analysis and Total Organic Carbon (TOC) Results for Merrimack Village Dam Impoundment**

	Sample / Location	Gravel	Sand	Silt	Clay	TOC
USFWS Samples	MVD-01	0.00%	95.42%	3.62%	0.96%	0.420%
	MVD-02	0.00%	97.32%	2.08%	0.60%	1.940%
	MVD-03	0.00%	85.18%	12.19%	2.63%	0.080%
	MVD-04	8.64%	91.00%	0.28%	0.09%	0.710%
	MVD-05	0.00%	68.68%	24.76%	6.56%	<0.000%
GS Sample	MVD-06 (Canal)	0.06%	98.46%	1.00%	0.48%	0.111%

## 6.0 Hydraulic Model

### 6.1 Purpose of Hydraulic Model

Hydraulic models of river systems are developed to predict water depths, velocities and water surface profiles under different flow events and conditions. A hydraulic model of the Souhegan River, from the confluence with the Merrimack to above Everett Turnpike, was developed for the following purposes:

- To predict water surface elevations and velocities in the MVD Impoundment (including the area where the dam currently sits) under different flow events for dam-in and dam-out<sup>10</sup> conditions.
- To determine the range of flows at which sediment in the MVD Impoundment becomes suspended and transported downstream under dam-out conditions.
- To determine if water velocities under dam-out conditions could scour existing infrastructure.
- To determine water depths in the wetland behind the fire department under dam-out conditions.
- To determine if depths and velocities are sufficient for fish to pass through the project area under dam-out conditions.
- To determine the extent of the impoundment.

### 6.2 Hydraulic Model Description

As noted earlier, the Federal Emergency Management Agency (FEMA) completed a Flood Insurance Study (FIS) of the Souhegan River, including Merrimack. Flood insurance studies were completed to predict the floodway (area of inundation) under a flood event such as the 50-, 100- or 500-year flood. The floodway area was predicted using a hydraulic model called HEC-2 (HEC-Hydraulic Engineering Center). HEC-2 has since been replaced by a new industry standard, HEC-RAS (Hydraulic Engineering Center-River Analysis System).

This section provides brief technical background on how HEC-RAS predicts water depths, velocities, and water surface profiles and methods used in modeling the dam-out condition. As such, this section contains technical terms relating to hydraulics and hydrology. Whenever possible effort has been made to simplify hydraulic concepts presented; however, if further clarification or explanation is desired, the reader is referred to the HEC-RAS Hydraulic Reference Manual (Brunner, 2002) or any standard open channel flow text.

HEC-RAS is designed to perform one-dimensional, steady, gradually-varied flow calculations in natural and man-made channels, as well as to perform unsteady flow routing, and elementary sediment transport computations. The model can simulate depths and velocities for a single reach, a branched system, or a full network of channels. HEC-RAS can simulate sub-critical, super-critical, and mixed flow regimes.

Hydraulic analyses performed by HEC-RAS are based upon a step-wise solution of the one-dimensional Energy Equation. In instances of rapid change in the water surface elevation causing turbulence and energy loss, HEC-RAS uses the Momentum Equation. In HEC-RAS, rapid changes in the water surface elevation may occur under the following conditions: bridge constrictions, inline structures (dams and weirs), confluence of two or more flows, rapid changes in channel bed elevation, and hydraulic jumps. Energy losses in the channel are associated with friction (solved with Manning's Equation) or with contraction and expansion (solved by multiplying a loss coefficient by the change in velocity head

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<sup>10</sup> Dam-out is referenced throughout this document and assumes that the entire spillway and apron would be removed—commonly called full dam removal.

between cross-sections). Flows over weirs and other inline structures (dams) are determined with the standard weir-flow equations. HEC-RAS also permits the modeler to include gate structures that accompany inline structures such as dams.

### 6.3 Model Input

Shown in Figure 6.3-1 is a plan map illustrating the original FEMA cross-sections used to develop the HEC-2 model. Gomez and Sullivan (GS) retained a paper<sup>11</sup> copy of the original HEC-2 input and output data and re-created the hydraulic model in HEC-2. The water surface profiles provided in the “recreated” HEC-2 model were verified against the original FEMA output data to ensure that the model replicated past results; the water surface profiles matched accordingly. Once verified, the recreated HEC-2 model was converted to HEC-RAS.

After conversion, the bridges, and dams were revised to work with the updated algorithms used in the most recent version of HEC-RAS. Due to the unique shape and location of the MVD and its apron in conjunction with the Chamberlain Bridge, the FEMA HEC-2 modeled the MVD as a cross-section rather than a bridge (for HEC-2, modeling dams as bridges with low chord openings small enough to prevent flow is the accepted procedure). GS maintained the FEMA HEC-2 representation, rather than updating the MVD to an inline structure format, because the geologic constraints caused by underlying bedrock and the unique shape of the MVD made the task of incorporating an inline structure impossible without affecting the hydraulic characteristics of the impoundment immediately upstream.

With the HEC-RAS model reformatted, it was run and the water surface elevations were compared to the FEMA HEC-2 output to ensure that the conversion was reasonably accurate. Shown in Table 6.3-1 is a comparison of the water surface elevations at each cross-section (as shown in Figure 6.3-1) from the original HEC-2 model relative to the HEC-RAS model. Table 6.3-1 shows the excellent agreement between HEC-2 and HEC-RAS in the area of effect of the MVD.

**Table 6.3-1: Comparison of the Original FEMA HEC-2 Model Water Surface Elevations (WSE) Relative to the New HEC-RAS Model for the 50- and 100-year flood flows**

X-section	HEC-2 Original WSE, 50-yr flood <sup>1</sup>	HEC-RAS New WSE, 50-yr flood	Difference in WSE, 50-yr flood	HEC-2 Original WSE, 100-yr flood	HEC-RAS New WSE, 100-yr flood	Difference in WSE, 100-yr flood
A	114.7	114.7	0.0	119.5	119.5	0.0
B	115.1	115.1	0.0	119.7	119.7	0.0
C	131.2	131.2	0.0	131.4	131.5	0.1
D	131.2	131.3	0.1	131.5	131.5	0.0

<sup>1</sup> Based upon the output from the “recreated” FEMA HEC-2 Hydraulic Model.

Once the model was properly formatted for HEC-RAS, the additional transects from our survey (T-1 through T-7) along the main channel of the MVD Impoundment were entered into HEC-RAS. The purpose of inserting these additional transects was to create a model that more accurately portrayed existing conditions. More than 20 years have passed since FEMA created the HEC-2 model for its 1979 FIS, and during that time maintenance activities such as dredging behind the stoplog gate to the canal and continued deposition have altered the impoundment bed. The secondary motive was to improve the precision of the cross-sections that HEC-RAS uses to compute water velocities, and depths. FEMA cross-sections display general trends in topography, producing results that are accurate enough to predict a floodway for a given storm; however, the FEMA depiction of the channel bed is rough and required

<sup>11</sup> Paper copies were obtained from microfiche.

enhancement for accurate prediction of water depths and velocities as well as scour analysis and determination of suitability for fish passage. The same datum was used for both the FEMA and GS cross-sections.

FEMA used Manning's "n"<sup>12</sup> values in the range of 0.03 to 0.05 for the main channel and values ranging from 0.07 to 0.1 for areas outside the banks. The higher roughness values assigned to the banks can be attributed to flow resistance caused by trees, shrubs, and grasses that line the banks. For the reach containing the MVD Impoundment, GS reviewed the Manning's "n" values assigned by FEMA and found these to be in an appropriate range. For consistency, GS used the same values for the added cross-sections.

After transects were entered into the HEC-RAS model, GS used available contour maps and the bathymetric map shown in Figure 4.3-1 to create upland areas and to depict the wetland and the wetland outlet. Ineffective flow areas were assigned to cross-sections that included the wetland (HEC-RAS River Station 18 through 19.3) to ensure that the wetland is not used by HEC-RAS to convey flow. The ineffective flow areas are set so that should the natural levee separating the wetland and the main channel become overtopped, the wetland would begin to convey flow through those cross-sections downstream.

## 6.4 Analysis and Findings

HEC-RAS was run with a mixed flow regime, capable of calculating both sub-critical and super-critical water surface profiles associated with the mild channel slope above the MVD and the steep slope at the MVD. The upstream boundary condition was set by the normal depth of flow far upstream of the impoundment. The downstream boundary condition was set by the water surface elevation of the Merrimack River at the confluence of the Souhegan River. The elevation was determined by FEMA in the Town of Merrimack FIS. The model was run for seasonal high (March, April, and May) and low (July, August, and September) flows as well as the 10, 50, 100, and 500-year flood flows determined by the FEMA FIS for the Souhegan River.

The HEC-RAS model was used to assess the channel response to seasonally high and low flows and flood events for three alternatives- dam-in, dam-out (sediment in place) and dam-out (sediment removed). The water surface elevations resulting from the dam-out alternatives were compared to dam-in water surface elevations to determine potential impacts on the channel, impoundment, existing structures, and wetlands.

### 6.4.1 Dam-In Results

The HEC-RAS model requires channel morphology information in the form of cross-sections (station, elevation data). In addition to the cross-sections collected as part of the FEMA study, the HEC-RAS model was supplemented with additional cross-sections that were collected as part of this study (T-2 through T-7). The supplemental cross-sections reflect the sediment and dam remaining in-place. Shown in Figure 6.4.1-1 is a plan map showing all of the cross-sections (FEMA and GS supplemental transects) used in the HEC-RAS model. HEC-RAS was run for the following flows:

- Drought Flow, 7Q10 flow= 12.8 cfs
- Summer Average Low Flow- August Mean Flow= 78 cfs

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<sup>12</sup> Manning's n is a dimensionless value that represents the roughness of a river channel. A rough channel (large boulders, large cobble) would have a high roughness value such as 0.09, whereas a smooth channel (silt) would have a lower roughness value such as 0.03.

- Average Annual Flow= 283 cfs
- Spring Flow- when anadromous fish are migrating upstream<sup>13</sup>, April Mean Flow= 770 cfs
- 2-year flood flow- 3,140 cfs
- 10-year flood flow- 6,900 cfs
- 50-year flood flow- 11,870 cfs
- 100-year flood flow- 12,460 cfs
- 500-year flood flow- 21,940 cfs

Flood flows at the MVD were taken as the flow at the confluence of the Souhegan River and Baboosic Brook, just downstream of the Chamberlain Bridge, as listed in the FEMA FIS for the Town of Merrimack, NH.

Table 6.4.1-1 is a summary of the flows, water surface elevations, average water depths and average velocities at each cross-section in the HEC-RAS model for flows of 12.8 cfs, 78 cfs, 283 cfs 770 cfs, and 12,460 cfs. Also, shown in Figure 6.4.1-2 is the water surface profiles for the same flows under dam-in conditions.

The dam-in model shows the MVDD Impoundment stretching from the dam to just below the Everett Turnpike Bridge. This model reflects the current hydraulic response (the “no action” alternative) to varying flows, including the inundation of the wetland (not visible in Figure 6.4.1-2) behind the Fire Station. Outside the influence of the MVD, the model of the Souhegan River reflects natural riverine conditions.

Table 6.4.1-1 shows that flow velocities in the impoundment are markedly slower than in reaches of the Souhegan River that are flow unimpeded. The slow velocities in the impoundment have caused sediment deposition (for the impoundment profile absent sediment, see Figure 6.4.3-2).

For the 500-year flood, the Souhegan River overtops the Chamberlain Bridge, which was shown to occur in the original FEMA HEC-2 model for existing conditions.

#### 6.4.2 Dam-Out Results (Sediment in Place)

When creating the HEC-RAS model for the dam-out alternative, the channel geometry beneath the MVD was estimated by hammering steel rods to the point of refusal at several locations behind the dam. It is suspected that there is a bedrock drop near the dam forming a hydraulic control. This hydraulic control will subsequently affect upstream water surface elevations, depths and velocities. For purposes of modeling, a composite cross-section was estimated to reflect the channel bed absent the sediment. A word of caution is worth noting with respect to the hydraulic analysis. The depth to bedrock immediately behind the dam (based on our sampling) will not reflect the true depth to bedrock directly beneath the dam. Ideally, corings through the dam (and upstream/downstream of the dam) would provide the necessary information to more accurately model bedrock controls beneath the dam. It is possible, for example, that the depth to bedrock directly beneath the dam is shallower than that located immediately behind the dam. Historically, dams were often located to take advantage of natural water control features, and were therefore constructed on top of bedrock outcroppings.

For the dam-out alternative, GS removed the cross-sections that formed the dam (HEC-RAS cross-sections 16 & 17), and updated cross-section 18 to include the outlet of the wetland. The composite

<sup>13</sup> As noted in the fisheries section, USFWS provided information on the timing of anadromous fish runs on the Merrimack River.

cross-section, created from the sediment depth measurements taken immediately upstream of the MVD on June 29 & 30, 2004, was then entered as cross-section 17.9, four feet upstream of the dam. Station 17.9 was then copied into the position of Station 17 as a rough estimate of the control formed by bedrock formations underlying the MVD.

Table 6.4.2-1 is a summary of the flows, water surface elevations, average water depths and average velocities at each cross-section in the HEC-RAS model for flows of 12.8 cfs, 78 cfs, 283 cfs and 770 cfs. Also, shown in Figure 6.4.2-1 is the water surface profiles for the same flows (plus the 100-year flow of 12,460 cfs) under dam-out conditions.

Table 6.4.2-1 shows that flow velocities in the stretch of the Souhegan River that is currently impounded by the MVD will increase upon removal of the dam. Under most flow conditions peak velocities occur at the ledge underlying the MVD. The increase in flow velocities will initiate sediment transport that had been blocked by the MVD. For more information on sediment transport and its effects on the Souhegan River, see Sections 6.5 and 6.6.

Dam removal will result in a lower water surface profile in the area of the current impoundment. Water surface elevations will drop from as little as two feet near the Everett Turnpike to as much as eight feet near the dam site. The lowering of the water level will result in dewatering of the wetland for the 7Q10, median August, mean annual, and median April flows; however, large flow events beginning with the 2-year flood will result in inundation of the wetland. The 500-, 100-, and 50-year floods will result in overtopping of the embankment that separates the wetland from the main channel of the Souhegan River.

Figure 6.4.2-2 shows the approximate location of the wetted area of the Souhegan River in plan view for the dam-in and dam-out scenarios. This figure represents the estimated location of the main channel of the Souhegan River for the mean annual flow in the short-term after the removal of the MVD. It is suspected that renewed sediment transport will have some effect upon the migration and eventual stable location of the channel bed in the short-term.

High velocities may occur in the upper impoundment for the 100-year flood event. The Everett Turnpike Bridge will cause a backwater that may drive flow velocities just downstream of the bridge in excess of 20 feet per second. Backwater from the ledge at the MVD site will force the formation of a hydraulic jump that will limit most velocities in the lower (downstream) portions of the impoundment to a range from 4 to 10 feet per second for the 100-year flood flow.

Modeling indicates that only the 500-year flood event will result in overtopping of the Chamberlain Bridge.

#### 6.4.3 Dam-Out (Absent Sediment) Results

The purpose of the dam-out (absent sediment) model is to depict the hydraulic effects of the unlikely situation where all the sediment in the impoundment is scoured. In reality, experience shows that all streams undergo both scour and deposition of sediment, and that pockets of sediment of varying sizes develop naturally even in river reaches undergoing significant scour. In addition, large pools within streams are areas where sediments commonly deposit. Thus, this analysis overestimates the amount of sediment lost from the system.

Table 6.4.3-1 is a summary of the flows, water surface elevations, average water depths and average velocities at each cross-section in the HEC-RAS model for flows of 12.8 cfs, 78 cfs, 283 cfs and 770 cfs. Also, shown in Figure 6.4.3-1 is the water surface profiles for the same flows (plus the 100-year flow of 12,460 cfs) under dam-out conditions.

For the dam-out (absent sediment) alternative, GS used the same sediment depth transects (Figures 5.1-1 through 5.1-7 and 5.1-9) to establish what we hypothesize was the native substrate before the MVD was constructed. This data represents the same transects used to supplement the FEMA FIS for the dam-in and the dam-out scenarios. Using the elevations of the native substrate effectively models the MVD Impoundment without sediment. Because no sediment depth information is available on the transects taken by FEMA for the Town of Merrimack FIS, FEMA transects in the impoundment were removed from the model.

Figure 6.4.3-1 shows that the bedrock ledge at the MVD site does form a hydraulic control, and potentially a small falls when the dam and sediment have been removed. The figure also shows a natural depression in the bedrock behind the ledge at the MVD. While the model output shows a natural backwater caused by the ledge resulting in a pool with a maximum depth of approximately eight feet, it is more likely that the sediment that currently fills this depression will not be scoured. When the ledge begins to exert control over the flows in the impoundment, high velocities causing scour will begin to decrease, eventually resulting in a stable channel (where rates of deposition and scour are equal).

The estimated, long-term channel (absent all sediment) under the mean annual flow is depicted in plan view in Figure 6.4.3-2. As shown, the wetted area behind the ledge causes a backwater that spans the width of the channel bed. Because we do not expect total scour to occur, it is likely that the area of greatest conveyance will remain along the southern bank of the channel because of a natural phenomenon in hydraulics that causes velocities transverse (flowing from bank to bank rather than in the direction of flow) to the flow resulting in scour along the outside bank of a curve and deposition along the inside bank directly across the channel.

Assuming that the model represents the long-term effects of dam removal, we can see in Figure 6.4.3-1 that the water surface elevations will continue to drop until the flow of the Souhegan River is nearly 10 feet lower than in its dam-in state (roughly 114.0 feet for mean annual flow). This lowered water level will result in dewatering the wetland behind the Fire Department. The natural embankment between the current wetland and the main channel of the Souhegan River should only be overtopped by the 500-year flood, though it is expected that the wetland would be inundated by the 100-, 50-, and possibly the 10-year flood events via its existing outlet. Without some form of outlet control, this inundation of the wetland will be temporary and water will exit the wetland as the flood recedes.

As in the dam-out scenario, the Chamberlain Bridge will be overtopped by the 500-year flood, though it is expected that smaller flood events will pass the bridge without overtopping.

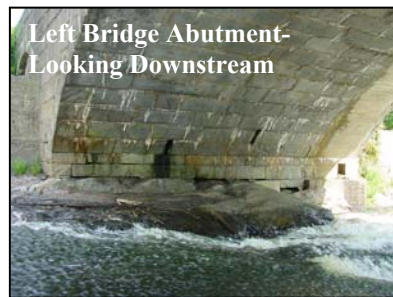
It should be noted that with the sediment removed, velocities in the upper impoundment, just below the Everett Turnpike, will be quite high for the 10-, 50-, and 100-year floods. The Everett Turnpike Bridge will act as a choke point, causing a substantial backwater that will drive the flow through the bridge. Once past the constriction, the large potential energy (caused by the increased depth of flow) will drive flow velocities to greater than 20 feet per second. The backwater caused by the ledge will cause the formation of hydraulic jumps (energy dissipation will occur) that should limit the velocities in the lower impoundment. The high velocities and hydraulic jump should not occur for the 500-year flood event because the backwater caused as the flow overtops the Chamberlain Bridge will propagate upstream to the Everett Turnpike Bridge.

## 6.5 Impoundment Scour Analysis

Because HEC-RAS is based on one-dimensional, steady, gradually varied flow, the software cannot account for flow velocities transverse to the main channel flow. This introduces limitations in evaluating

preferential deposition and scour, and in predicting channel formations such as bars or scour holes. Transverse velocities are often difficult to determine with accuracy, so most applicable potential scour and sediment transport calculations are based upon empirical formulae utilizing average channel velocities.

It is important to note that the scour and deposition of sediments are processes that occur naturally in all rivers and streams, and are a key to maintaining a healthy riverine environment. Dam construction, operation and removal can upset the natural equilibrium between erosion and deposition of sediments to the detriment of the downstream and upstream ecosystems. Therefore, it is important to plan carefully how to manage impounded sediments.



Scour in the channel below the dam is not a significant issue owing to the presence of natural bedrock formations and concrete retaining walls. This is particularly true for the Chamberlain Bridge which has its foundations set upon bedrock (see pictures at left and above). The Chamberlain Bridge would not be affected by abutment scour should the dam be removed. If the impoundment is unprotected, the channel upstream of the MVD will be subject to scour with increased flow velocities upon dam removal. The impoundment will experience a lower water surface elevation as the impoundment reverts to riverine conditions.

Because the sediments in the impoundment are loose deposits of sand and non-cohesive silt/clay, the current channel bed elevation, which is largely determined by impounded sediments, will drop as soil pore pressure decreases in conjunction with receding water-levels. The settling will be augmented by erosion processes that carry loose sediment deposits downstream towards the Merrimack River. Flood water elevations will drop as the channel bed lowers through settling and erosion.

If sediments are allowed to be naturally transported downstream, depositional zones will occur in slow velocities areas. There is sufficient velocity to carry sediment directly below MVD; however, there is a depositional area 300 feet downstream of the MVD. This stretch of the Souhegan River is characterized by a mild slope and its channel bed and banks, which are formed entirely of sand.

## 6.6 Sediment Transport and Sediment Management

### 6.6.1 Sediment Transport Background

Background on the process of sediment transport is provided here to help educate readers on some of the transport findings discussed later. In-depth calculations of sediment transport within the MVD impoundment are provided later in this document. It should be noted that the full sediment transport study, including all of the detailed calculations are available in Appendix D- Sediment Transport Study.

Sediment transport is the process by which sediment is eroded from an upstream location and transported downstream. Though it sounds simple, it is difficult to quantify. Unlike most areas of study in hydraulics, sediment transport has an almost unlimited number of variables ranging from usual hydraulic properties (flow, velocity, channel slope, bank slope, channel depth, and channel width) and sediment properties (size, density, shape, angle of repose, cohesiveness, size distribution) to atmospheric conditions (air and water temperature, presence of ice and ice jams) various anthropogenic factors (presence of levees and dams, urban development, and dredging activities) and random factors such as turbulence.

The following is a brief description of the governing principles of sediment transport and their application to the feasibility of removal of the MVD.

As noted earlier, sediment transport is a naturally occurring, continuous process in all streams. Streams are in dynamic-equilibrium between sediment deposition and scour, usually resulting in a stable channel configuration. In upland areas of the Souhegan River watershed physical, chemical and biological erosive forces break down rock to provide a continuous source of sediment for transport. This coarse sediment is collected by runoff and eventually enters tributaries and the mainstem of the Souhegan River. From here the coarse sediment is degraded until it is small enough to be transported by the local flow velocity. Flow velocity varies with the channel gradient and the magnitude of flow, which is always changing. Usually, sediment deposits exhibit a range of sediment sizes from fine clays to boulders because the river passes varied geologic deposits. This range of sediment sizes leads to armoring, whereby fine particles are carried away, eventually leaving large sediment on top to protect the channel bed from further erosion.

While sediment transport is continuously occurring, it does not occur at a constant rate. The variation in flows—lower flows in the dry summer months, higher flows in the spring—leads to varying rates of sediment transport. During times of low flow, channel velocity is also low, limiting the capacity of the stream to transport sediment. During periods of extreme high flow, the flow in the river channel is deeper, promoting the development of a laminar boundary layer that protects the channel bed from scour. While peak flows (for instance, the 100-year flood) do have a higher sediment transport capacity, they occur infrequently. At what flow does most sediment transport occur? It is typically referred to as “bank-full flow”, a flow that occurs approximately every 1.5 years that has a high enough flow velocity to initiate particle motion but is shallow enough to allow turbulent flows to interact with the channel bed.

Channel stability, whether flow will cause sediment transport, is determined by comparing the tractive force needed to initiate sediment motion to the shear force that flow creates against the channel bed and banks. As in most areas of sediment transport, there are a multitude of available methods for determining stability, but two that have proven reliable are Hjulstrom and Shields. Hjulstrom developed curves that describe the maximum permissible velocities (without causing scour), while Shields developed a curve that describes the conditions for incipient motion. With a known sediment size distribution, it is possible to determine the velocity needed to initiate erosion or deposition. Once sediment has begun to move, it can be transported as either suspended load, sediment entrained in the flow and actually lifted from the channel bed, or bed load, sediment that is dragged along the bottom or tumbles downstream with the current.

Equations that describe sediment transport, whether they predict bed formations, rates of transport, stable channel design, or geomorphology, all derive from one of two methods of description: theoretical or empirical. In the former, it is important to know the assumptions and simplifications inherent in the development of the theory, and in the latter it is important to know what type of river or rivers were used to develop the equations.

Two bedload formulas that provide a range of potential sediment transport are the Meyer-Peter-Muller formula and the Einstein-Brown formula. Both formulas use the sum of the sediment size fractions to estimate the total bed load. The Meyer-Peter-Muller formula was developed for gravel-bed rivers, so it yields a conservative estimate for particle sizes smaller than 6.4 mm. A more finite, precise estimate of sediment transport is provided by the Einstein-Brown formula based on fluid mechanics and probability.

## 6.6.2 Sediment Transport Study and Analysis

Sediment samples in the MVD Impoundment are relatively uniform and dominated by sand size particles. The particle size distributions determined by both sediment samples and pebble counts for the surveyed

cross-sections are presented in Table 6.6.2-1. D15, D50 and D85 refer to the percentage of sediment that is finer than a given size. The sediment analysis contracted by the USFWS used 2 sieves and a hydrometer test to sort the five samples (MVD-01, MVD-02...MVD-05) into size fractions. The size fractions are developed by sorting the material according to sediment grain-size and then determining the percentage of the sediment by mass that is finer than the given sieve size. The following grain sizes were used by the USFWS to separate the four major classifications of sediment size (gravel, sand, silt, and clay):

- 2.0000 mm (Very Fine Gravel / Very Coarse Sand)
- 0.0600 mm (Very Fine Sand / Coarse Silt)
- 0.0060 mm (Very Fine Silt / Coarse Clay)
- 0.0004 mm (Very Fine Clay / Fines)

The pebble count was conducted by observing and recording the sediment sizes on the channel bottom every few inches, starting at the river-right bank and proceeding across the Souhegan River until the flow was too deep to continue sampling.

The partial sieve and hydrometer analysis contracted by USFWS and the pebble count performed by personnel from GS and UNH were converted to standard grain-size distribution curves.

It should also be noted that in Table 6.6.2-1 the station and transect numbers are given. The station number references stations within the HEC-RAS model, whereas the transect numbers reference the sediment depth measurement locations discussed in Section 5.1. Transects 8 and 9 are located below the Everett Turnpike Bridge at and above the upper extent of the MVD Impoundment. The grain-size data for transects 8 and 9 are based on pebble counts; no sieve analysis was conducted.

**Table 6.6.2-1: Particle Size Distributions by Station and Transect**

HEC-RAS Station No.	Sediment Depth Measurement Transect No.	D15 (mm)	D50 (mm)	D85 (mm)
	1	0.10	0.37	1.1
18.3	2	0.11	0.37	1.1
19.3	4	0.06	0.28	1.1
19.6	5	0.09	0.37	1.6
20.6	7	0.018	0.17	0.9
	8	0.9	5.7	210
22	9	17	140	500

The results of the grain-size distribution curves developed indicate the relative uniformity of the sediment in the MVD Impoundment. Approximately 70 to 98% (see Table 5.4-1) of the material in the impoundment is sand with virtually no larger material. Transects 8 and 9, taken at the upper extent of the impoundment, display much larger sediment, generally ranging from coarse gravel to medium-sized boulders. These samples are indicative of the native substrate underlying the MVD Impoundment.

As noted in Section 6.6.1, determining the bankfull flow is critical for establishing the stable channel configuration. It is at this flow that much of the channel formation and erosion occurs. Larger flows above bankfull have similar channel forming functions, but are generally stabilized in overbank conditions where vegetative stabilization, thick boundary layer, and high roughness play a large role. For a large variety of rivers throughout North America, bankfull channel cross section geometry has been

shown to correspond with a discharge that has a recurrence interval of approximately 1.5 years in the annual flood series (Dunne and Leopold, 1978). Data for the 2-year flood flow was modeled in HEC-RAS for this project. These data, a representative low flow (7Q10), a mean annual flow, and flood flows of 2-, 10- and 100-years were used to evaluate sediment transport and particle stability. Inspection of topographic maps of the Souhegan River, in combination with an understanding of the regional physiography and stream channel patterns, guided the sediment transport and management assessments.

### Channel and Particle Stability

Based on the particle size distribution and HEC-RAS model outputs (depth, velocity), particle stability analyses were performed. Stability analyses are consistent with field observations that indicate that sedimentation of fines is occurring within the backwater, disrupting sediment transport continuity, resulting in aggradation in the impoundment above the dam. Particle stability was determined by shear stress assessment per the American Society of Civil Engineers (ASCE Manual 54 and EM 1110-2-1418). The Shield's parameter, used to determine the particle size that will experience incipient motion (Simons et al, 1982) upon dam removal, was compared to Hjulsstrom's method to establish ranges of anticipated sediment stability for the range of flows discussed previously.

**Table 6.6.2-2: Comparison of Minimum Particle Size for Incipient Motion for 7Q10-Q100 by Shields and Hjulstrom for Dam Removal**

HEC-RAS Cross Section	Flow (cfs)									
	7Q10		Mean Annual		2-year		10-year		100-year	
	$D_s$ (mm)		$D_s$ (mm)		$D_s$ (mm)		$D_s$ (mm)		$D_s$ (mm)	
	Shields	Hjulstrom	Shields	Hjulstrom	Shields	Hjulstrom	Shields	Hjulstrom	Shields	Hjulstrom
22 / 9	4.42	2.20	51.00	17.00	131.00	>100	169.00	55.00	173.00	>100
21	0.00	0.00	1.26	1.10	11.00	10.00	23.00	16.00	44.00	23.00
20	37.00	9.20	25.00	9.00	13.00	8.90	13.00	8.00	20.00	13.00
19	0.00	2.10	5.06	4.00	28.00	15.00	41.00	16.00	22.00	16.00
18	0.00	0.00	0.63	0.90	16.00	9.10	34.00	18.00	74.00	27.00

Table 6.6.2-2 shows the diameter of a stable particle for a given flow ( $D_s$ ) for transects throughout the impoundment (transect 18 is approximately 45 feet upstream of the dam, and 22 is 210 feet downstream of the Everett Turnpike) for the Dam Out condition. In general Hjulstrom's method was the lower end of the size range. As a result, Shield's method was chosen as a conservative evaluation—it predicts that the same flow will move a larger grain size and consequently more sediment. Table 6.6.2-2 illustrates that stable particles will range from coarse sand for the 7Q10 flows, to large cobble for the 2-year flow. Hydraulic modeling supports the idea that the 2-year flow may be the channel forming event. For nearly every flow event at every cross-section transport of coarse sands can be expected.

Channel conditions above and below the impoundment exhibit bed armoring by bedrock overlain with gravel, cobble, and boulders. Particle stability analyses indicate that the sections above and below the impoundment are stable and armored; however, materials within the impoundment can be expected to move across the full range of flows. The bed slope can be expected to become steeper as the sediment is transported from the downstream end of the impoundment.

Dam removal will reestablish sediment transport continuity and enable periodic flooding to purge unprotected sections of the channel bed of fine sediments.

## Bedload Sediment Transport

The selection of appropriate sediment transport equations is vital to estimating sediment load in rivers. Because the MVD Impoundment is largely filled with sand, the majority of sediment transport will occur as bedload (rather than suspended load). The range of dry-weight bedload transport rates was determined using the Meyer-Peter-Muller (MPM) and the Einstein-Brown (EB) methods. Of the two, the EB method is more representative for sand-sized sediment.

Both methods calculate the weight of sediment transported per unit of time per unit of width (lbs/ft/sec) of the river for a given cross-section. The rate of sediment transport varies continuously as rivers flow from upstream to downstream. Tables 6.6.2-3 through 6.6.2-5 show the rates of sediment transport for Transects 2, 7, and 9, located in the lower impoundment, the upper impoundment, and the channel above the impoundment, respectively.

Note that the rates of sediment transport increase sharply from the mean annual flow to the 2-year flood flow. The increase in bedload can be attributed to the turbulent interaction of the flow with the channel bottom. Because the bank-full flow (modeled as the 2-year flood flow) occurs, on average, 5 to 7 times as often as the 10-year flood flow it is responsible for the largest quantity of sediment transport.

The large disparity between the EB estimate and the MPM estimate of sediment bedload transport rates displayed in Tables 6.6.2-3 through 6.6.2-5 is common. As discussed previously, the MPM applied to this case yields an over-estimate because it was developed with data from steep-sloped gravel-bed rivers. The important correlation between the two estimates lies in the similar pattern they follow in assigning sediment transport rates to each flow event: the sharp increase from the mean annual flow to the bank-full flow, and the dominant position of bank-full flow in terms of gross sediment transport over time.

**Table 6.6.2-3: Bedload Sediment Transport Rates for Transect 2**

<b>Return Period</b>	<b>Flow</b>	<b>Einstein-Brown <math>q_{bw}</math></b>	<b>Meyer-Peter and Muller <math>q_{bw}</math></b>
(YRS)	( cfs )	(lb/ft/sec)	(lb/ft/sec)
7Q10 Flow	12.8	0.000	0.000
Mean Annual Flow	283	0.002	0.073
2-yr Flood Flow	3140	0.198	6.981
10-yr Flood Flow	6920	1.979	20.372
100-yr Flood Flow	12500	1.979	66.008

**Table 6.6.2-4: Bedload Sediment Transport Rates for Transect 7**

<b>Return Period</b>	<b>Flow</b>	<b>Einstein-Brown <math>q_{bw}</math></b>	<b>Meyer-Peter and Muller <math>q_{bw}</math></b>
(YRS)	( cfs )	(lb/ft/sec)	(lb/ft/sec)
7Q10 Flow	12.8	0.000	0.000
Mean Annual Flow	283	0.003	0.085
2-yr Flood Flow	3140	1.614	3.855
10-yr Flood Flow	6920	1.979	11.563
100-yr Flood Flow	12500	1.979	29.919

**Table 6.6.2-5: Bedload Sediment Transport Rates for Transect 9**

<b>Return Period</b>	<b>Flow</b>	<b>Einstein-Brown <math>q_{bw}</math></b>	<b>Meyer-Peter and Muller <math>q_{bw}</math></b>
(YRS)	( cfs )	(lb/ft/sec)	(lb/ft/sec)
7Q10 Flow	12.8	0.025	0.198
Mean Annual Flow	283	2.604	12.863
2-yr Flood Flow	3140	4.797	68.800
10-yr Flood Flow	6920	5.572	113.689
100-yr Flood Flow	12500	1.979	106.513

#### Effects of Dam Removal on MVD Impoundment Sediment

Sediment transport is especially important for dam removals with the sediment accumulation and deposition in the impoundment. Because the lifespan of dams is long, the volume of sediment build-up can be large, although this varies from project-to-project and with the dam location within the watershed. Dam removal will cause flow velocity in the MVD Impoundment to increase from near stagnation to nearly 7 ft/s. The increase in flow velocity is what drives sediment transport. In the MVD Impoundment, the sediment is of highly uniform size, as much as 97% sand by mass. The uniform size coupled with the continuous erosion caused by increased velocities will result in scour.

Nearly 81,000 cubic yards of sediment is currently impounded by the MVD; however, not all of this sediment would be naturally swept downstream. We hypothesize that the channel will not experience rapid lateral migration; rather it will scour until the current impoundment returns to an equilibrium state. The HEC-RAS Dam-out geometry (absent sediment) indicates that a backwater pool will remain in the same location as the MVD Impoundment, thereby protecting a significant portion of the impounded sediment from scour.

#### Effects of Dam Removal on Downstream Reaches

In the short term, it is reasonable to expect scour within the MVD Impoundment after removal. The channel 300 feet downstream of the MVD is formed entirely of sands similar to those found in the MVD Impoundment. Because this reach has been subject to sand deposition, it is likely that sand scoured from the MVD Impoundment will be deposited in the channel and overbanks downstream. Over time, the reconnection of the original sediment transport regime will lead to an increased bedload in the Merrimack River.

While a period of initial instability is expected as a stable channel is formed in the MVD Impoundment, a stable sediment transport regime should be established without adversely affecting the downstream channel and habitat.

#### 6.6.3 Sediment Management Analysis

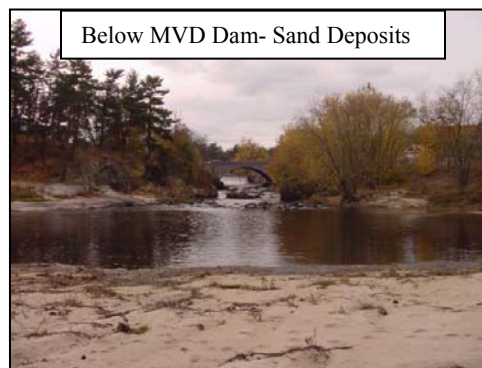
Natural processes are generally more efficient at attaining and maintaining channel stability than are man-made solutions to those same problems. The processes of scour and deposition occur in all flowing natural bodies of water and they help to maintain a healthy ecosystem by transporting nutrients downstream and creating habitat diversity to support a large variety of plants and wildlife. Promoting the natural processes that lead to stable channel development and habitat diversification is of paramount importance in designing and implementing a successful sediment management plan for removal of the MVD.

The MVD Impoundment is filled with approximately 81,000 cubic yards of sediment. While some of this sediment will be scoured during dewatering of the MVD Impoundment and during the period after dam removal, some of the impounded sediment will remain. This remaining sediment will likely be protected by a backwater caused by a ledge at the dam site.

Approximately 90 percent of the impounded sediment is uniformly sand-sized. This uniformity all but eliminates natural channel bed armoring processes, whereby preferential scour of fine sediment leaves a layer of larger gravel, cobble, and boulder protecting the channel bed. The only possibility for armoring to occur is if sediment (gravel size and larger) is carried into the impoundment by flood events. As this process will take time, it is likely that sediment transport will be continuous under all but low flows until a stable channel configuration is attained. Gradual channel widening and channel bed incising, leading to a reduced channel slope, will eventually result in a stable channel configuration.

To put the volume of sediment in the MVD Impoundment into a frame of reference, USGS sediment transport data was attained for the Merrimack River below Concord River at Lowell, MA (Site 01100000). The drainage area at the sample site is 4,635 mi<sup>2</sup>, and it lies just downstream of the Pawtucket Dam. The site collected suspended sediment concentration data from 1967 through 1972. The data shows that the peak 7-day suspended sediment transport at the site was 58,543 cubic yards of sediment, roughly the same order of magnitude of sediment located in the MVD Impoundment. This estimate excludes bedload transport (the usual method of sand transport in rivers) which would boost the total sediment load carried by the Merrimack River at this location. The data also confirms that peak sediment transport occurs during periods of high flow (spring melts or flood events). These results are substantiated by the findings of the sediment transport analysis found in Section 6.6.2.

While large sediment deposits are not in evidence in the rapids immediately above and below the MVD Impoundment, site visits indicate that large quantities of sand have been deposited at the mouth of the Souhegan River. Beginning approximately 300 feet downstream of the MVD (at the base of the rapid) the channel bed, banks, and overbanks of the Souhegan River are all formed by sands of the same size as found in the impoundment (see Appendix A for several photographs of sediment deposition below Chamberlain Bridge and near the Merrimack River confluence). Large deposits of sand stretch hundreds of feet from the channel. The presence of large sand deposits downstream suggests that sand deposition occurs naturally in this reach. The low velocities caused by the MVD prevent scour under most flows, though large amounts of sand appear to pass the MVD during high flow periods in the spring. It is also important to note that no spawning grounds will be destroyed by letting natural sediment transport processes scour sand from the impoundment and deposit it at the mouth of the Souhegan River because the channel bed is already sand.



The channel is formed by bedrock overlain with sand and other migrating sediments. Lateral migration of the channel bed will be constrained by channel entrenchment on both banks, though some increase in sinuosity is expected as the channel migrates to attain an equilibrium slope. Slope reduction is accomplished naturally in two ways: 1) incision lowers the channel slope by scouring the channel bed, and 2) migration lowers the channel slope by increasing the length of river between two points. Natural channel stability will be reached as the channel slope is reduced by a combination of the above methods and channel widening.

Geomorphic inspection suggests that while initial channel definition and sediment transport will occur, nick point migration will be limited by exposed bedrock above and below the impoundment and

underlying the channel bed. Nick point migration refers to the process of the streambed unraveling through down-cutting; the process of nick point migration can occur in the upstream or downstream directions, and occurs when there is no particle stability under commonly occurring flows or new hydraulic conditions.



Before removal of the MVD is undertaken, it will be important to initiate several sediment protection-related activities. Investigation of the canal structure and outlet, dredging sediment immediately upstream of the canal gate structure, dewatering of the impoundment, bank stabilization, and revegetation will all need to be initiated or completed before dam removal can begin.

The stoplog gate and sluice gate that act as low-level outlets for the MVD are blocked by as much as 12 feet of sand. Sediment was removed from this location in 1991 when the sluice gate was installed but has been deposited over the past 13 years to the extent that an island of sand nearly 2 feet above the water surface has been deposited in the same location. Sediment has also been deposited in the canal to a depth of nearly 3 feet. Before the impoundment can be dewatered, the sediment from behind the canal gate structure must be removed. As noted earlier, the sediment chemical analysis and subsequent toxicity testing indicates that contaminants are not likely to be readily bioavailable and pose no risk to downstream ecosystems. Thus, preference is given to allow natural transport of sediments within the impoundment.

When the gates are fully operable, the impoundment will be dewatered slowly by allowing flow to pass the gates and pour over the canal wall (functioning as a lateral weir). At this point there remains a question as to the fate of flow in the canal when it was operable. Flow that passes under the Chamberlain Bridge eventually meets a log wall. Because the adjoining property on the opposite side of this wall was once a chemical plant, it will be important to thoroughly investigate the fate of flow in the canal, plan for its use, and apply for permits accordingly. Operation of the canal will also be important during removal of the apron below the MVD, as previous dam removals have shown that removal of an apron subject to flow may unduly increase costs and prolong projected removal time. With this in mind, locating or creating an alternative path for sediment and water flow during dam and apron removal may reduce costs and is therefore recommended.

Based on the magnitude of flow that can be conveyed through the stop log and gate, there is sufficient hydraulic capacity to convey average monthly flows to allow dewatering of the impoundment from July through October. Dewatering of the MVD Impoundment may be possible during the month of June, but only if June is uncharacteristically dry. Dewatering is proposed for early July so that vegetative reclamation of the newly exposed channel banks may progress during the growing season.

During dewatering, bank failure is often a problem. Bank failure is a function of bank material, material shear strength, slope angle, climate, vegetation and root density, water, and time. Water pore pressure (a function of water depth) provides a force resisting bank failure, so lowering the impoundment water surface elevation (WSE) will remove a stabilizing force. Water entrained in the soils acts to increase the weight of the bank and reduce friction resisting bank failure, further destabilizing the bank. To mitigate these destabilizing forces, the rate of dewatering should be slow, allowing entrained water to drain from the soils at the same approximate rate as the water level in the impoundment is dropped. The rate of dewatering should not exceed 0.5 feet per day (the approximate hydraulic conductivity of the bank materials) so as to prevent bank failure. The maximum depth of dewatering will be approximately 8 feet, so 16 days will be required to fully dewater the impoundment.

It is important to initiate re-vegetation as soon as possible after the impounded soils are exposed. If the impoundment is dewatered during summer months, it is expected that revegetation will be rapid. Native grasses and shrubs that grow on currently exposed mid-channel bars will take root in newly exposed soils. As such, revegetation may occur through natural processes, or through active reseeding and planting of the exposed sediments with native grasses, shrubs, and trees. Active reseeding may be the best alternative to prevent the emergence of invasive species. Purple Loosestrife (*Lythrum Salicaria L.*) has been identified above and below the dam, so more extensive planting and protection may be required to limit invasive species spreading throughout the impoundment. Biodiversity in plantings will guarantee that some of the planting thrive, ensuring that plantings are successful in protecting exposed soils.



Sensitive locations that may be subject to bank failure should receive further attention before dam removal. Stabilization of these areas may require live-staking, coir fascine, and erosion control matting in addition to seeding and planting to stabilize banks. Live staking provides immediate stability and reduces soil moisture while providing long-term stability with root development. Live-staking is most successful if instituted during the spring or fall because the stakes will be in a dormant growth-phase and will not be damaged while being placed. Coir fascine will protect the toe of the bank while accumulating sediment to stabilize the toe. Coir fascines, made from coconut husks, will biodegrade slowly over 3 to 6 years. Erosion control matting will provide immediate slope stabilization and protect soils while root structures are developing. Incorporation of large woody debris may also help to create habitat diversity and protect the right bank from failure by undercutting and scour.

Bioengineering methods are preferred to older methods of bank stabilization (e.g. riprap revetment, or structural solutions) for several reasons. First, bioengineering methods are more adaptable and work to enhance natural processes rather than altering them. Second, bioengineered methods of bank stabilization are less costly than more established methods. Third, bioengineering methods do not require as much maintenance as structural methods (drop structures, dikes, etc.) because the design life is short with the expectation that the ecosystem will begin to establish a natural equilibrium during that time. Lastly, proper selection of materials will ensure that all materials are biodegradable such that no cleanup or removal cost is incurred in the future.

While the above solutions should help to stabilize the channel banks prior to full recovery and reclamation of the ecosystem, it is important to plan and apply for permits in such a way as to have flexibility should an unexpected situation arise. In extreme cases it may be necessary to mechanically alter the bank slope or provide for a hard engineering solution such as an energy dissipation structure or using rounded rock to protect the channel bed and bank.

The process of sediment management in concurrence with dam removal is envisioned as the following steps:

1. Construct a coffer dam to seal off the wetland and canal inlet structure
2. Dredge sediment immediately upstream of the canal structure to make them operable
3. Retain dredged sediment for use onsite as topsoil (high organic content at wetland outlet)
4. Removal of the coffer dam (maintain a dam blocking the wetland outlet)
5. Open the stoplog gate and the sluice gate to dewater the impoundment

6. Concurrent to dewatering, apply bank stabilization procedures discussed above, using previously dredged soil as necessary
7. Construct a coffer dam to protect the MVD as it is removed
8. Remove the MVD and the apron
9. Perform necessary channel forming dredging, or mechanical bank stabilization
10. Remove coffer dam
11. Reconnect upstream channel to desired outlet at former dam site

Concurrent to the dewatering of the impoundment, sediment sampling and testing should be conducted. This is important because of the nature of sediment deposition: more recent layers of sediment overlay older layers of sediment. During sediment testing conducted by the USFWS notes were made that the sediment was virtually impenetrable, so samples were taken mostly from surficial deposits. Random testing should be held concurrently with dewatering and dam removal to reduce the likelihood that pockets of contaminated sediments are not swept downstream during the initial channel incision.

The above analyses do not evaluate the capacity of the Merrimack River to cope with a renewed sediment source; however, the Souhegan River routinely carried sediment to the Merrimack River prior to the damming of the Souhegan River. The core vision of the presented sediment management plan is the reconnection of sediment transport continuity, while protecting the MVD Impoundment from excessive scour through a controlled dewatering process and vegetative stabilization of the banks. Certainly, sediment will be transported to the receiving waters, but the volume and rate of transport will be determined by the frequency and magnitude of flows, and the success of vegetative stabilization in the impoundment.

## **7.0 Infrastructure/Aesthetic/Safety and Flood Issues**

### **7.1 Infrastructure**

A concern with any dam removal project is the location of existing utilities (water lines, power lines, sewer systems, underground utilities) that could be impacted during the removal process. This could include infrastructure in the location of MVD, and infrastructure that could be exposed due to the dewatering and rechanneling of the river above MVD after removal.

#### Water lines

The town of Merrimack near the MVD is serviced by the Merrimack Village District Water Works. Mr. Bob Kelley of the District was contacted to determine if water lines passed in the vicinity of the dam or through the impoundment. According to Mr. Kelley, water lines in the project area are contained within the Chamberlain Bridge, thus dam removal would have no impact.

#### Sewer lines

The Merrimack Department of Public Works was contacted with respect to the location of sewer lines in the project area. Mr. Don Hamel of Public Works indicated that no sewer lines traverse the Souhegan River, either near the dam or within the impoundment. A pump station is located east of the MVD on Railroad Drive. The pump station conveys wastewater along the railroad tracks. Separate sewer lines are located on the north and south side of the river. Given the location of the sewer lines, it is expected that dam removal would have no impact on the sewer lines.

#### Transmission/Power Lines

PSNH indicated that three power lines cross the Souhegan River between the Chamberlain Bridge and the Everett Turnpike: a 115kV line (W-157), and two 34.5kV lines (323 and 3164). Visual inspection of the impoundment yielded a set of lines that cross the Souhegan River on the upstream side (west) of the Chamberlain Bridge, and two sets of lines that cross the MVD Impoundment upstream of the mid-channel bar formations (approximately 600 feet downstream from the Everett Turnpike bridge). No additional power lines were identified during our site visits or by PSNH.

It should be noted that if dam removal were to proceed, Dig Safe System, Inc. would be called in advance of any demolishing work. Dig-Safe will then contact all utilities in the project area, who are then required to flag their utilities within 72 hours prior to excavation work.

### **7.2 Aesthetics**

As noted at the June 2003 meeting, many members of the public feel the dam and flowing water is aesthetically appealing and provides scenic views throughout the changing seasons. One of the common concerns with dam removal projects is the aesthetic appeal of the site immediately following dam removal. Dam removal usually results in a temporary exposure of sediments (i.e., mud flats) due to the dewatering of the impoundment. This is generally unavoidable and tends to be visually unappealing immediately following a dam removal. However, firsthand experiences at dam removal projects in New Hampshire and nationwide have documented that these exposed sediments typically revegetate within a few weeks during the growing season and are soon “greened up.” It is common for members of the public to be cautious at dam removal due to aesthetic concerns. If dam removal proceeds, it is recommended that “before” and “after” photographs of past dam removals be shared with the public. In addition, a combination of appropriate computer software and site-specific technical knowledge can be

used to generate digitally enhanced “after” photographs of what the project could look like after dam removal.

### 7.3 Public Safety/Icing Issues

Although the dam is considered low hazard it does not necessarily mean no hazard. Sudden failure could still present a safety issue, particularly if recreation users or anglers are located below the dam or in the impoundment. In addition, an uncontrolled sudden release of water and sediment could have detrimental impacts on the downstream ecology and would promote a far greater degree of sediment transport than is expected.

The MVD slows the river velocity resulting in sheet ice developing along impoundment—see Photos 11 through 15 in Appendix A. It is unknown if removal of the dam could increase velocities enough to promote frazil ice development; however, the potential for ice-jam formation where the channel narrows at the Chamberlain Bridge is a potential concern. Ice jam formation can occur during spring thaws when thermal expansion causes break-up of border ice formations concurrent with high flows caused by melted snow and precipitation. NHDES contacted the Army Corps of Engineers Cold Regions Research and Engineering Laboratory regarding icing issues at several dams considered for removal, including the Merrimack Village Dam. .

In September 17, 2002 Kate White, a Research Hydraulic Engineer with the Army Corp of Engineers Colds Regions Research and Engineering Laboratory (CRREL) sent a letter to NHDES regarding icing issues on various dams considered for removal. In the letter, Ms. White summarized the ice regime in New Hampshire Rivers, and provided more specific information relative to ice jams on the Souhegan River. Below are excerpts from her letter to NHDES:

“The ice regime on similar rivers in New Hampshire can be described as follows: periods of intense cold in early winter result in the formation of frazil ice and the growth of sheet ice along the river’s border. The frazil ice is transported downstream to some location where the transport capacity of the river is exceeded, at which point it begins to deposit. This generally occurs at the upstream end of a dam impoundment where there is a sudden slope change from steep to mild. As cold temperatures continue, an ice cover made up of sheet ice and frazil ice will form in all but extremely turbulent reaches of river. This ice cover will break up mechanically as a result of sudden large increases in flow, or it can simply melt in place. Mechanical breakup in New Hampshire rivers usually requires a combination of precipitation and snowmelt. Mechanical breakup can result in the formation of ice jams if the transport of the broken ice is slowed or stopped. This often occurs at the upstream end of an impoundment, where the ice cover has been thickened by frazil deposition and is more resistant to breakup”.

Kate White’s summary of ice jamming on the Souhegan is summarized below.

“A search of the CRREL Ice Jam Database (<http://www.crrel.usace.army.mil/ierd/icejam/icejam.htm>) revealed that five ice jams have been reported on the Souhegan River. Ice jams have also been reported on Baboosic Brook and the Merrimack River in Merrimack, indicating an active ice regime, so that it is highly likely that more jams have occurred than have been reported. Three of the ice jams on the Souhegan River were located in Merrimack, one upstream from the USGS gage (01094000), and two reported at the gage. The jam upstream from the gage was apparently formed at an oxbow in the river about 1.5 miles upstream from the Everett Turnpike, while the jams at the gage were reported as being due to ice jams at the gage. These ice jams formed somewhere in the reach between the Merrimack Village Dam and the gage, most likely at the upstream end of the impoundment. It is possible that removal of the dam could change the ice regime of the river so that ice that might have jammed at the upstream end of the impoundment is transported downstream, where it could jam in the backwater from

the Merrimack River. Observation of the ice regime at the Merrimack Village Dam and the downstream reach, including the adjacent Merrimack River, is *highly recommended* before removal in order to assess the potential for increased downstream jamming”.

As noted earlier the Chamberlain Bridge appears to have been constructed after the MVD, as the second (smaller) span of the bridge conveniently spans the power canal. A potential concern that may require additional evaluation is if the MVD is removed, ice jams that previously occurred upstream could be transported to the where the river channel narrows through the main span of Chamberlain Bridge. As described in Section 14, additional analyses relative to ice jamming may be warranted.

Another issue to consider is the concrete apron extends from the MVD to just below the Chamberlain Bridge. Historic information suggested that the apron was extended downstream to prevent spray from accumulating on Chamberlain Bridge. If the MVD is removed there could be an issue in the winter if spray were to cause ice-up on the bridge and hence create a safety issue.

#### 7.4 Flood Issues

As noted earlier, FEMA conducted flood studies to determine the flood elevations in the Souhegan River above the MVD. The flood studies reflect the dam-in condition. Removal of the dam and sediment will result in lowering the flood elevations in the area above the dam. If the dam is removed FEMA may require a Letter of Map Amendment (commonly called a LOMA) showing the revised flood elevations. Consultation with FEMA on this issue will be necessary if dam removal moves forward.

#### 7.5 Fire Use

According to the Merrimack Fire Department, the MVD Impoundment is not used for fire use or the flushing of pumper trucks. Thus, removal of the dam would have no impact on fire demands.

## 8.0 Fisheries Resources

### 8.1 Resident Fish

Native species of fish in the Souhegan River include blacknose dace, brook trout, brown bullhead, chain pickerel, common shiner, common white sucker, creek chub sucker, fallfish, golden shiner, longnose dace, pumpkinseed, redbreast sunfish, spottail shiner and yellow perch (SRWR, 1997). Introduced species include brown trout, largemouth bass, smallmouth bass, margined madtom, yellow bullhead, and rainbow trout (SRWR, 1997). In addition, the river is stocked annually by the NH Fish and Game (NHFG) with brown trout, rainbow trout and eastern brook trout. In 2003, 1+ age trout were stocked along the Souhegan River in Merrimack, Milford, Amherst, Wilton, Greenville and New Ipswich. The NHFG records report 10,260 trout were stocked in the river- 2,740 rainbow trout, 3,290 eastern brook trout and 4,230 rainbow trout in 2003. Virtually all of the trout in the Souhegan River Watershed are the result of the stocking program (Souhegan River Nomination, 1999). When released, the trout are typically of a legal size for angling, representing what is called a "put and take" program.

### 8.2 Merrimack River Anadromous Fish Restoration Program

The MVD represents the first barrier to upstream fish passage on the Souhegan River. There are two dams on the Merrimack River located below the Souhegan River confluence. The Essex Dam in Lawrence, MA is located approximately 33 river miles downstream of the confluence. The Pawtucket Dam in Lowell, MA is located approximately 21 river miles downstream of the confluence. Approximately 11 river miles upstream of the Souhegan River confluence is Amoskeag Dam in Manchester, NH. All three dams are equipped with upstream and downstream fish passage structures, thus diadromous fish can migrate to the mouth of the Souhegan River. Diadromous fish spend part of their lives in freshwater and saltwater. These include anadromous and catadromous fish. Anadromous fish (such as river herring, Atlantic salmon, American shad, Sea lamprey) spawn and develop in freshwater, before returning to the ocean. Once anadromous fish reach sexual maturity, they repeat the cycle and return to freshwater to spawn. Alternatively, catadromous fish (such as American eel) spawn and develop in saltwater, and move into freshwater to grow.

The Massachusetts Division of Fisheries and Wildlife (MDFW) monitors the number of returning diadromous fish and counts the number of American shad, Atlantic salmon, striped bass, Sea lamprey, gizzard shad and river herring<sup>14</sup> that utilize the upstream passage structures at Essex and Pawtucket Dams. The NHFG is responsible for obtaining counts at Amoskeag Dam. Shown in Table 8.2-1 are the returns of river herring, Atlantic salmon and American shad from 2000-2004.

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<sup>14</sup> River herring collectively refers to two fish species: blueback herring and alewife.

**Table 8.2-1: Anadromous Fish Returns at the Essex, Pawtucket and Amoskeag Dams, Merrimack River, 2000-2004**

	Essex Dam			Pawtucket Dam			Amoskeag Dam		
	River Herring	Atlantic Salmon	American shad	River Herring	Atlantic Salmon	American shad	River Herring	Atlantic Salmon	American shad
2000	19,405	85	69,257	673	<sup>1</sup> N/A	12,716	316	<sup>1</sup> N/A	39
2001	1,550	84	73,840	58	<sup>1</sup> N/A	7,578	<sup>2</sup> N/A	<sup>1</sup> N/A	<sup>2</sup> N/A
2002	526	57	54,560	0	<sup>1</sup> N/A	5,283	0	<sup>1</sup> N/A	<sup>2</sup> N/A
2003	10,607	120	55,620	0	<sup>1</sup> N/A	6,276	0	<sup>1</sup> N/A	<sup>2</sup> N/A
2004	15,051	122	36,593	7,448	<sup>1</sup> N/A	11,028	N/A	<sup>1</sup> N/A	<sup>2</sup> N/A

<sup>1</sup>N/A- all Atlantic salmon are captured at Essex Dam for brood stock, thus no adults are passed upstream.

<sup>2</sup>N/A- typically there is little monitoring of river herring and American shad at the Amoskeag Fishway, counts are not available.

Source: Joe McKeon, USFWS

As expected, more fish are passed at the lowermost Essex Dam compared to the Pawtucket Dam. The USFWS has been conducting studies and are making recommended changes to the Pawtucket passage structure with the goal of passing more fish. Similarly, changes were made to the Essex Dam upstream passage facility in the 1980s resulting in much improved passage efficiency, although the table above does not reflect this trend as it represents the last 5 years of data.

The Souhegan River is an important part of the Merrimack River Anadromous Fish Restoration Program and is considered one of the most productive rivers in the Merrimack watershed. Restoration efforts of anadromous fish on the Merrimack River have been on-going for several years. The upper reaches of the Souhegan River and its tributaries provide the appropriate habitat - gravelly, sloping bottoms, water temperatures, oxygen levels and food sources - for excellent growth and survival of Atlantic salmon fry and juveniles. On average, 125,000 Atlantic salmon fry are stocked in the Souhegan River and tributaries including Stony Brook, Blood Brook, and King Brook annually. In addition to stocking fry, prespawn American shad and river herring have been transferred and/or stocked by the USFWS and NHFG. In June 2003, 600 adult American shad were transported and released in the Souhegan River in Amherst.

Adult salmon are stocked in the Merrimack River for anglers. A member of the Fire Department has seen salmon located in holding pools immediately below Chamberlain Bridge. In fact, they have observed salmon attempt to ascend the MVD, however, they have been unsuccessful due to the lack of a holding pool just below the dam. It is suspected that because the concrete apron extends well downstream (beneath a portion of Chamberlain Bridge), the salmon cannot sustain the swimming speed to negotiate both the apron and the dam.

The Merrimack River Basin Fish Passage Action Plan for Anadromous Fish, January 1988, calls for the construction of upstream passage at the MVD when 15,000 shad/year (on average) pass through the Amoskeag Dam fishway over a 5-year period. To date, upstream passage has not been required as the number of returning shad is well below the 15,000 trigger. It is assumed that once the number of shad passing the Pawtucket Dam increase, the intensity of monitoring of the Amoskeag fishway will increase to determine if the 15,000 shad/year threshold is achieved.

In addition, the Souhegan River is integral to the extremely successful USFWS Adopt-A-Salmon Family Program that uses a watershed approach for environmental education. Classrooms are given Atlantic salmon to raise during the year which are then released into the Souhegan River in the spring. At present, the Souhegan River is the main release site for the program that currently involves approximately 25 schools in Massachusetts and New Hampshire. The fry are stocked by state and federal natural resource personnel, volunteers, and school children

Removal of the MVD would open approximately 14 miles of free-flowing mainstem Souhegan River. The USFWS estimates that dam removal would restore about 100 surface acres of habitat for migratory fish. The USFWS also estimates that it would be feasible to attain 50 shad per acre of habitat, or 5,000 returning shad to the restored habitats in the Souhegan River if the MVD were removed (Ken Sprankle, USFWS, June 2003 Presentation).

### 8.3 Historical Distribution of Diadromous Fish

According to the USFWS American shad, Atlantic salmon, Sea lamprey, blueback herring, alewife and American eel are believed to have historically utilized the Souhegan River basin. To confirm whether sea-run fish were historically present in the Souhegan River numerous contacts were made and research was conducted. Contacts were made with the USFWS (Ken Sprankle and Joe McKeon), NHFG (Jon Greenwood), Souhegan River Watershed Association (George May), Nashua Regional Planning Commission (Angela Rapp), and Merrimack townspeople (Florence Brown, Chuck Mowers). All contacts were asked about historical accounts of diadromous fish in the Souhegan River, and if they knew of other written documentation. In addition to personal communications, several books were reviewed and visits to some town libraries were conducted. Books that were reviewed included (full references are in Section 15):

- *A Week on the Concord and Merrimack River*, 1849.
- *The History of Manchester formerly Derryfield, in New Hampshire*, 1851.
- *The Merrimack River; Its Sources and Its Tributaries*, 1869.
- *History, Town of Wilton*, 1888.
- *Biological Survey of the Merrimack Watershed*, 1938.
- *Fishing in New Hampshire*, 2003.
- *Three Centuries on New Hampshire's Souhegan River, Birthplace of Ideas and Industry*, 2004.

In general, no party was aware of specific historical accounts of sea-run fish, but recommended some of the references listed above.

It is clear from the references that diadromous fish were present in the Merrimack River. It was reported that spring spawning runs on the Merrimack River included salmon, shad, lamprey and alewives. In Jack Noon's book, *Fishing in New Hampshire*, he writes: "Once in New Hampshire sea-run fish would continue to branch off into various tributaries. Those that kept ascending the Merrimack eventually reached Franklin, where the Merrimack River begins. Of the Merrimack River fishing sites in New Hampshire, Amoskeag Falls in Manchester was the largest and most famous. There the configurations of channels, rocks and small islands right where the fish were slowed in their upriver progress by the falling water gave fishermen good chances to get close to them with hand nets and eel hooks. Though all accounts describe the fishing at Amoskeag Falls as spectacular, few include any numbers of fish caught." Noon indicated that most likely "we will never get a sense of the vastness of the spawning runs arriving at Amoskeag Falls when the spot was an Abenaki subsistence fishery." He notes that there is the strong likelihood that the first white men fishing for salmon at Manchester- probably in the 1720s- would have encountered an already depleted salmon fishery due to Massachusetts fishermen and commercial harvesting.

There is little documentation of the extent of anadromous fish populations since they thrived during the Abenaki Indian era. It seems the first white settlers to the Souhegan River valley over fished the river and soon depleted the plentiful fish resources. From the Wilton Town History- "That's why, in 1797, residents of the town petitioned the State Legislature to help preserve what they saw as the Merrimack's

dwindling resources. It seems that too many folks were rigging nets (or weirs) that snared fish in the river, particularly Salmon, Shad & Alewives... whereby they have been much decreased for many years past".

From Henry David Thoreau's book it states "The salmon once frequented the cold shaded branches of the Merrimack River while the Shad and Alewife sought the smaller, warmer streams and ponds to spawn." According to Thoreau, the settlers in Lowell blocked anadromous fish from swimming up the Merrimack River toward the Souhegan River with the creation of an industrial center. "Salmon, shad and Alewives were formerly abundant here . . . until the dam . . . and the factories at Lowell, put an end to their migrations hitherward. . . . Perchance, after a few thousands of years, if the fishes will be patient, and pass their summers elsewhere . . . nature will have leveled . . . the Lowell factories, and the Grass-ground River [will] run clear again."

With respect to the Souhegan River, the Wilton Town History offered the most insight regarding the presence of anadromous fish in the Souhegan River. In the introduction section of the Wilton Town History it states "It is a tradition that in early times alewives, shad and salmon penetrated as high up the river as Greenville." This statement suggests that alewives, shad and salmon were able to ascend other barriers in the Souhegan River on their migration to Greenville, such as Wildcat Falls and other sharp gradient drops. Later in the town history it states "Of fishes, the largest, the salmon, were caught in the Souhegan as late as 1773-4." Thus, although there is no information on the population of anadromous fish there is documentation suggesting that salmon, alewives and shad were historically present in the Souhegan River above the MVD.

## 9.0 Wetland Resources

### 9.1 Wetland Description

The large wetland system (see Figure 9.1-1) located behind the Merrimack Fire Station, adjacent to the Souhegan River, was delineated in the field in accordance with the Corps of Engineers Wetland Delineation Manual (ACOE 1987), in June 2004. Federal wetland classifications were assigned according to criteria published by the USFWS in Classification of Wetlands and Deepwater Habitats of the United States (Cowardin et al. 1979). National Wetland Inventory maps for this area indicate that the subject wetland is classified as palustrine open water (POW) and palustrine forested, broad-leaved deciduous (PFO1) in accordance with the USFWS wetland classification system. Most of the open water sections of this wetland system are fed by overflow from the Souhegan River, which is further supported by the impoundment created by the MVD. Downstream of the dam the river bottom is primarily bedrock immediately beyond Chamberlain Bridge, and beyond that short stretch, the river moves more slowly and sand bars have developed. Shown in Appendix E are pictures of the wetlands in the impoundment.

Aquatic plant species within the open water sections of the wetlands include duckweed (*Spirodela polyrrhiza*), white pond lily (*Nymphaea odorata*), other water lilies (*Nuphar* sp), pickerelweed (*Pontederia cordata*) and arrowhead (*Sagittaria latifolia*). Ferns in the forested and scrub-shrub wetland areas include cinnamon fern (*Osmunda cinnamomea*), royal fern (*Osmunda regalis*), and sensitive fern (*Onoclea sensibilis*). Other emergent plant species include bladder sedge (*Carex intumescens*), umbrella sedge (*Cyperus strigosus*), green bulrush (*Scirpus atrovirens*), soft rush (*Juncus effuses*), broad-leaved cattail (*Typha latifolia*), skunk cabbage (*Symplocarpus foetidus*), and jewelweed (*Impatiens capensis*). Shrub species along the edges include northern arrowwood (*Viburnum recognitum*), highbush blueberry (*Vaccinium corymbosum*), speckled alder (*Alnus rugosa*), and witch hazel (*Hamamelis virginiana*). Wetland tree species include red maple (*Acer rubrum*) and American elm (*Ulmus americana*). Upland tree species adjacent to the wetland areas are dominated by eastern white pine (*Pinus strobus*) and eastern red oak (*Quercus rubra*).

The wetland areas were visited during June 2004, when the water levels in the Souhegan River were still very near the seasonal high levels, due to an unusually wet spring. These areas were visited again in early August 2004. As the summer progresses, water levels in the river begin to drop, and the area and depth of standing water within the wetland behind the fire department also begins to diminish. So, during much of the growing season, in most years, this wetland typically undergoes gradual changes, converting from a mostly open water shallow marsh, to a marsh dominated by emergent vegetation with much smaller areas of open water.

From the MVD upstream to the Everett Turnpike Bridge crossing, the banks of the Souhegan River are primarily comprised of excessively drained loamy sands. The embankment along the rivers edge is also fairly abrupt and white pines, oaks and maples are the dominant vegetation types. Although there are scattered wetland plants located sporadically along the edge of the Souhegan River, there is only one other wetland area between the MVD and the Everett Turnpike Bridge. This wetland area is actually part of the river, but is different enough to warrant description. This area is located over ¼ mile upstream of the dam, and about 200 feet downstream of the Everett Turnpike Bridge, and was formed when the river cut a secondary channel for a short distance (see Figure 9.1-1). This likely occurred during an extended period of high flows. During most of the year, especially during the summer months, this secondary channel does not have any continuous water flowing through, the water then stagnates and algae forms on the surface. Aquatic and emergent wetland vegetation has also developed in some areas along this channel and is thickest near the upstream entrance to the channel. This vegetation includes broad-leaved cattail, pickerelweed, and speckled alder along the edges.

There are also islands (see Figure 9.1-1) that have developed along this section of the river, created by sands deposited over time and changing shape depending on river flow velocities. Most of the area covered by these islands is vegetated with grassy plants. These islands are not considered to be jurisdictional wetlands since they lack hydric soils and are not dominated by wetland vegetation.

## 9.2 Wildlife Observations and Habitats

Site visits in the early summer of 2004 indicated the following species use the wetland areas within the impounded wetland behind the fire station; Canada geese (*Branta canadensis*); Hooded merganser, mother with three chicks (*Lophodytes cucullatus*); bullfrog (*Rana catesbeiana*); fish – species unknown, but likely smallmouth and largemouth bass and/or perch; anecdotal evidence of muskrat (*Ondatra zibethicus*), mink (*Mustela vison*), otter (*Lontra canadensis*), and white-tailed deer (*Odocoileus virginianus*) was also noted; as well as evidence of past beaver (*Castor canadensis*) activity (none recent). Although not noted during the site visits, this wetland would also provide good habitat for a variety of wading birds and ducks including; black ducks (*Anas rubripes*), mallard ducks (*Anas platyrhynchos*), wood ducks (*Aix sponsa*), blue-winged teal (*Anas discors*), and great blue heron (*Ardea herodias*). This wetland, in conjunction with the surrounding forested wetland and the adjacent upland areas, also provides essential habitat for many species of amphibians including; eastern newts (*Notophtalmus viridescens*), spotted salamander (*Ambystoma maculatum*), green frog (*Rana clamitans*), spring peeper (*Hyla crucifer*); and reptile species such as; snapping turtle (*Chelydra serpentina*), eastern painted turtle (*Chrysemys picta picta*), and eastern box turtle (*Terrapene carolina*).

## 9.3 Threatened and Endangered Species

In assessing the presence of Threatened and Endangered species in Merrimack, GS reviewed the New Hampshire National Heritage Bureau (NHNHB) report on “Rare Plants, Rare Animals, and Exemplary Natural Communities in New Hampshire Towns”. Shown in Table 9.3-1 is a list of rare, threatened and endangered plants and animals in the town of Merrimack. Investigation of the NHNHB list reveals three plant species (Bald Spike Rush – *Eleocharis erythropoda*; Small Bidens – *Bidens discoidea*; Smooth Bidens – *Bidens laevis*), one reptile species (Blanding’s Turtle – *Emydoidea blandingii*), and one fish species (Swamp Darter – *Etheostoma fusiforme*) as candidates likely to be encountered in the impounded wetland. Of the candidate species, only one plant species (Small Bidens - *Bidens discoidea*) is listed as threatened or endangered. It is suggested that, should dam removal move forward, a more detailed field study be conducted, prefaced by further coordination with the NHNHB.

## 9.4 Wetland Functions and Values

Functional values of the two primary wetland types within the impounded wetland adjacent to the fire station were assessed in accordance with the US Army Corps of Engineers (ACOE) Highway Methodology Workbook Supplement: Wetland Functions and Values, A Descriptive Approach (ACOE, 1995). Based on this review, the primary functions and values exhibited by the open water wetland community includes the functions of flood storage, sediment/toxicant retention, nutrient transformation/retention, fish and shellfish habitat, sediment/shoreline stabilization, wildlife habitat, recreation, and visual/aesthetics values.

The primary functions and values exhibited by the forested and scrub-shrub wetland areas would include groundwater discharge, sediment/toxicant retention, shoreline stabilization and wildlife habitat.

## 9.5 Impacts and Recommendations

If the MVD and sediment build-up at the wetland outlet behind the fire department is removed, the water levels in the wetland will drop significantly. The existing channel bed elevation near the wetland outlet is approximately 121.0 feet with the water surface elevation of 122.8 feet (122.8 feet is the spillway crest elevation). The sediment composition at the wetland outlet is sandy and susceptible to scour and hence transport downstream under higher flows. A steel rod was hammered to refusal along a transect at the wetland outlet to determine the depth to refusal as shown in Figure 5.1-1. The depth to refusal is near elevation 112.8 feet, thus the wetland would become dewatered. The lowest elevation of the wetland, based on the bathymetric survey, is at approximately elevation 120 feet—again this would suggest that the entire wetland would become dewatered.

The major wetland system depends primarily on the backwater conditions created by MVD. There is some supplemental surface flow entering the wetland from the surrounding hillsides. However, this flow is likely inadequate to supply sufficient water to maintain the current water regimes, especially if the sediment at the outlet is removed. Presently, much of this wetland is classified as Palustrine open water (POW) with some Palustrine scrub-shrub (PSS) and Palustrine forested (PFO) areas along the edges. Removing MVD would convert most of the open water wetland into more scrub-shrub and/or forested wetland. It is equally likely that some of the current scrub-shrub and forested wetland areas would gradually convert to upland.

Wildlife habitat within the open water wetland areas would also be altered if the dam were removed. Instead of an aquatic habitat supporting fish, waterfowl, amphibians, and reptile species, the converted wetland would be changed to a more terrestrial environment.

One alternative that may maintain the existing water levels is the construction of a vegetated swale (inflow channel) that provides a steady supply of water from the river to the wetland area during periods of high flow. It should be clearly noted that a detailed analyses of this alternative has not been investigated- the information presented herein is very conceptual at this juncture. A swale could be constructed within the narrow peninsula that currently separates the Souhegan River from the wetland. The swale must be designed to allow water to enter the wetland during periods of high flow, but prevent “backflow” after filling. Figure 6.4.1-1 includes a plan view of possible locations for the swale.

To avoid stagnation and eutrophication in the wetland, it is important to maintain an outlet so that water exchange is possible during high flow and precipitation events. A control structure may be necessary at the current wetland outlet to maintain current water surface elevations. Depending on more detailed engineering analysis of the outlet control structure, protection of the outlet during dewatering of the MVD impoundment may be necessary to avoid scour. To prevent damage to the existing wetland ecosystem, outlet control measures should be constructed before dam removal is undertaken. If this concept is to be given further consideration, then more detailed engineering and environmental studies would be required.

It should be noted that any wetland maintenance solution must be made with the understanding that water surface elevations in the present impoundment will be affected by dam removal, which will cause the water surface elevation to drop by several feet. Any dredging or scouring of the MVD Impoundment will cause water surface elevations to vary from levels predicted by HEC-RAS, potentially making a gravity-flow swale infeasible. It should also be noted that even with the swale in place, water surface elevations in the wetland will vary according to how much inflow the wetland receives. It is possible that during a drought or period of low precipitation the water level may drop substantially, or the wetland may dry out entirely until a high-flow event replenishes the waters therein.

Property issues would also have to be considered in determining the feasibility of wetland protection. In addition, it will take some time for the river channel to reestablish itself near the location of the potential vegetated swale so the “inlet” elevation will require time to natural stabilize—in other words designing a solution at this juncture may be premature until a stable channel is formed.

According to Town of Merrimack Contract Assessor, the lands behind the fire station (including the wetland and the peninsula separating wetland from the Souhegan River) are the property of the school district.

## **10.0 Recreation Resources**

It was not in the scope of work to evaluate the level of recreation use of the impoundment created by MVD, but some general information is provided herein. The evaluation of recreation resources was based on qualitative feedback from the public during our field visits as well as former documents, such as the Environmental Assessment completed by the Federal Energy Regulatory Commission (as part of a study that considered adding hydroelectric power to the MVD). Recreational use of the project area consists of swimming, canoeing and fishing. Members of the fire department also noted that people fish for smallmouth bass in the wetland behind the fire department. During site visits, anglers were seen downstream of the Chamberlain Bridge.

There are no developed recreational facilities or formal public access areas at the project site. Presently, informal access to the river occurs along both banks near Route 3. To our knowledge, no formal permission for fishing or swimming access has been granted by any of the property owners above the dam. In addition to swimming and fishing, the wetland behind the fire department may afford opportunities for passive bird watching and other forms of nature observation.

## 11.0 Historic Resource Study Requirements

### 11.1 Consultation Requirements

Projects (such as the removal of the MVD) that require a federal permit or that are receiving federal funding or assistance must coordinate with the New Hampshire Division of Historical Resources (DHR), in accordance with the National Historic Preservation Act. This coordination is needed to determine whether any properties that could be affected by removal of the MVD are eligible for listing to the National Register of Historic Places. Properties that are greater than 50 years old, such as the MVD may be eligible for listing to the National Register. Compliance with the National Historic Preservation Act is required of most dam removal projects since the U.S. Army Corps of Engineers (Corps) requires permits for activities that involve placing fill in waters of the United States.

The project's lead federal agency will be determined by whether any federal agencies are providing funding or technical assistance in the project (e.g. United States Fish and Wildlife Service, National Resource Conservation Service, National Marine Fisheries Service) or if the federal involvement is only through the permitting process (Corps 404 permit). At this juncture, no lead federal agency has been identified. However, once (and if) the lead federal agency is determined, the preliminary historic resources information will be provided to the State Historic Preservation Office.

The DES River Restoration Program and the DHR collaborated to develop "*Generalized Guidelines for Research and Report: Scope of Work for Proposed Dam Removals Pertaining to Historical and Archaeological Resources*"- see Appendix F for a full copy of the guidelines.

The purpose of the historic preservation review process as defined under state law RSA 227-C:9 and Section 106 of the National Historic Preservation Act (NHPA) of 1966, as amended (16 U.S.C. 470), implemented by the Federal Advisory Council on Historic Preservation's (ACHP) procedures, is to balance the public interest in historic preservation with the public benefit from a variety of governmental initiatives.

If consideration for dam removal proceeds further, there must be early consultation with the DHR. The DHR will also require an assessment of the potential impacts to cultural and historic resources resulting from dam removal. Sections 11.2 and 11.3 contain a brief summary of the studies that would be required by the DHR.

### 11.2 Phase I Assessment of Historic, Architectural and Engineering Resources

The Phase I assessment requires a qualified architectural historian to complete a Project Area Form for submittal to DHR for their review and approval. Briefly, the information for the Project Area Form includes:

- Background research on the history and evolution of the dam and study area,
- Visual assessment of the project area including the dam (photo-documentation),
- Description of the dam and other historical resources present within the study area (such as Chamberlain Bridge). Historical resources could include standing structures, foundations, bridges, abutments, etc.
- Description of the possible effects on the historic viewshed.
- Once the above is completed, the Project Area Form including text, maps, and photographs would be sent to the lead federal agency and the DHR for review and approval.

It should be noted that if any resources are part of a larger historic district, the evaluation is typically extended outside of the impact area to define that district.

### 11.3 Phase I Archeological Assessment

A Phase I Archeological Reconnaissance-level survey is typically divided into two sub-phases (Phase IA and IB).

The purpose of the Phase IA archeological assessment is to define all known or potential archeological resources that may be impacted by removal of the MVD. Similar to the historic assessment, a qualified archaeologist would conduct the study.

Generally, Phase IA studies require the following:

- Background research typically consists of reviewing archaeological site files at the DHR for known archaeological resources, both Native American and historical sites.
- An evaluation of the possible impacts to areas upstream and downstream of the dam after removal. Dam removal may result in disturbance to upland areas and riverine areas due to demolition equipment and potential mechanical dredging of sediment in the impoundment. These activities have the potential to disturb archeological resources. Removing the MVD will also lower impoundment water levels, which has the potential to expose artifacts. Removal will also result in higher velocities through the impoundment and thus there is the potential to erode sensitive streambank sites.
- A detailed project map with the area of impact must be defined including the areas proposed for access, staging and fill/removal disposal.
- A visual assessment of the proposed project area with regard to archeological resources is required including a site description and photo-documentation.
- A detailed map is needed to define the study area including known historic and archeological resources in close proximity.
- The DHR Archeological Inventory Forms must be completed.

Depending on the findings of the Phase IA study, a Phase IB study may be required. The level of effort recommended by the DHR in Phase IB generally includes subsurface testing.

## 12.0 Hydropower Resources

### 12.1 Past Hydropower Activity at Merrimack Village Dam

In conversations with various members of the public and as expressed at the June 19, 2003 public meeting, some parties are interested in potential development of the MVD for hydropower generation. In the 1980s and 1990s various hydropower developers considered installing turbines to generate electricity, but in the end the economics of the project were not justified.

Shown in the bullets below is a timeline of activities pertaining to the hydropower development of the MVD. All correspondence relating to hydropower development is attached in Appendix G. By way of background, any developer seeking to install turbines for generation must consult with federal, state and local resource agencies. Hydropower projects of certain size are regulated by the Federal Energy Regulatory Commission (FERC). In the case of developing the MVD for hydropower, FERC and the resource agencies are required to evaluate the impacts hydropower development would have on environmental, recreation, aesthetic, and archeological/historic resources. FERC is charged with seeking a balance between power and non-power resources.

- On December 15, 1983, the Souhegan Hydropower Company filed with FERC an application<sup>15</sup> for license of a minor (less than 5 megawatts, MW) unconstructed project at MVD. On November 9, 1984, Pennichuck Water Works, Inc filed with FERC a competing license application. Essentially both developers were competing to utilize the MVD site for hydropower.
- On February 1, 1988, FERC conducted an Environmental Assessment (EA) to determine the impacts of installing hydropower generation would have on fish, wetland, wildlife, visual and recreation resources.
- On November 28, 1988, FERC issued an order allowing PWW to develop the site. FERC's rationale for selecting PWW is that the projected annual generation was greater than the Souhegan Hydropower Company. Based on the PWW license application, they predicted that the average annual generation from the project would be 3,573 megawatt hours (MWH). The generation estimate was based on raising the water level an additional 2.5 feet by installing flashboards.

The FERC Order contained "Articles" that stipulate a timeline for constructing the project and requirements to mitigate environmental impacts. Major license article included a) construction of the project must be completed in two years, b) the project must be operated in a run-of-river mode meaning that inflow to the dam must instantaneously equal outflow, c) develop a plan to monitor impoundment levels to ensure run-of-river operations, d) construction of upstream and downstream fish passage facilities and e) conduct effectiveness studies to determine how effective the installed passage facilities are at passing fish.

- On September 24, 1992, PWW opted not to develop the site, stating that it was not economically justified. The license was surrendered thus leaving the site open for competition again.

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<sup>15</sup> A license application includes a summary of how the proposed project would be developed, its form of operation, a summary of the project resources (fish, wildlife, wetlands, aesthetics, recreation, archeological, historic), streamflow information, projected generation and proposed studies to evaluate the impacts of project operations on various resources.

- On April 14, 1993 Wilton Hydro Electric Company sought a preliminary permit to install turbines at the site, but on November 7, 1994, FERC cancelled Wilton Hydro's preliminary permit since progress reports were never provided.

## 12.2 Cost Considerations for Hydropower Development

No other hydropower developers have considered the site since 1993. If the site were again pursued for hydropower generation, the developer would have to consider the costs associated with capital expenditures, the FERC licensing process, and the value of baseload hydropower generation in today's energy market. Listed below is a brief summary of the issues that would require investigation if a developer pursued the site. This is not a complete list but represents the major tasks involved with constructing and licensing a hydropower facility.

- There would be capital expenditures associated with renovating the existing project works<sup>16</sup>, retrofitting the existing facility, purchasing turbine(s), potential construction of upstream and downstream fish passage facilities, and installing a switchyard and transmission lines.
- There would be costs associated with licensing the project with FERC, as well as legal fees and engineering design needs.
- There would be annual costs associated with operation and maintenance, administration, license fees, and taxes.
- The value of baseload power in today's market would have to be considered and the expected annual generation (in MWH) would have to be quantified.
- The regulatory climate for obtaining a license on a project today is different than in the 1980s. The Environmental Assessment conducted in 1988 was rather simplified compared to today's standards. It is expected that the developer would be required to conduct more rigorous studies to evaluate the impact hydropower generation would have on environmental, recreational, archeological/historical, and aesthetic resources.
- It is likely that a seasonal instream flow would be required directly below the dam for aesthetic purposes and to protect aquatic resources. The instream flow would reduce the amount of water conveyed to the hydropower station, resulting in less generation than estimated by PWW in their previous application.
- The licensee may be required to conduct follow-up studies once the project is constructed such as determining the effectiveness of upstream and downstream fish passage facilities, installing gages to confirm operations, etc.

It is not in the scope of this study to conduct an economic assessment of developing the site for hydropower. If another entity considers purchasing MVD with the goal of generating electricity, it is recommended that a detailed study be undertaken to evaluate project economics.

## 12.3 FERC Dam Safety Concerns

It should be noted that the dam safety requirements of FERC and the state can vary. Generally, FERC dam safety requirements are more stringent than state requirements. In fact, as summarized below, FERC independently investigated the stability of the MVD and the ability of the dam to meet FERC dam safety guidelines. The FERC New York Regional Office inspected the facilities on January 18, 1984. Although the NHDES Dam Bureau classifies the dam as low hazard, based on the FERC inspection they considered MVD as a significant hazard potential. The FERC staff's stability analyses showed that the dam does not have adequate sliding factors of safety for normal conditions, normal conditions with an ice loading,

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<sup>16</sup> The existing power canal is silted in, and the gates controlling flow in the canal would have to be operational.

normal conditions with earthquake loadings and flood conditions. The FERC staff recommended that a special article be included in any license granted, requiring the licensee to begin modifying the dam to adhere to FERC's engineering guidelines within one year of license issuance. Thus, it would appear that if the facility were used for hydropower generation additional measures would be required to stabilize the dam.

### 13.0 Affected Property Owners

The town of Merrimack provided property maps, including lot numbers, of the project area as shown in Figure 13.0-1. The town also provided the name and mailing address of all property owners abutting MVD and the impoundment up to the Everett Turnpike Bridge (the upstream extent of the impoundment). If dam removal occurred, these property owners would be directly impacted. Letters were sent to each property owner, summarizing the purpose of this feasibility study and explaining the potential changes to the impoundment if dam were removed. Property owners were also notified that field work was conducted during the summer 2004.

If dam removal were to occur the impoundment created by the dam would revert to riverine conditions and would expose lands currently inundated. Parties have inquired as to the property tax implications of this scenario. In talking with Merrimack Assessor Mr. Brett Purvis, it is our understanding that property tax consequences will be consistent with the property lines laid out in language from the land Deed. Residents are advised to obtain a legal opinion to determine if adjoining lands “created” by a drop in the Souhegan River water surface elevation will have tax implications.

A copy of the Pennichuck Water Works deed is shown in Appendix H. The deed indicates that PWW does not own property inundated by the impoundment, rather ownership is restricted to the confines of the dam and power canal. Information from the deed follows:

“The concrete dam in the Souhegan River at Merrimack, New Hampshire, situated immediately westerly of U.S. Route 3, extending from bank to bank in said river and including the sluiceway and headgate situated at the westerly end of said dam, and the ground beneath all of the foregoing structures in the bed of said river, extending from the southwesterly line of the right of way of said U.S. Route 3 to a line five (5) feet beyond and westerly of the line of the footings of said dam, the bounding line extending from bank to bank in said river in a curve concentric with the curve of the upper face of said dam.”

The parcel of land is described in the deed as follows:

“Beginning at a point in the southwesterly line of said U.S. Route 3 on the southerly side of the granite bridge crossing the Souhegan River in said Merrimack, at the southernmost granite post in the wing wall of the railing of said bridge, which railing is situated on the southwesterly or upstream side of said bridge; thence southeasterly by the southwesterly line of said highway twenty-five (25) feet to a point; thence westerly at right angles with the center line of the highway of the other land of the grantor to a point on the southeasterly bank of the Souhegan River; thence northerly by said bank of the Souhegan River to said post at the point of beginning.”

## **14.0 Next Steps (if any)**

### Formal Dam Inspection and Repair Estimate

As noted above, the Dam Bureau issued a Letter of Deficiency (LOD) and requested Pennichuck Water Works to complete work necessary for the dam to be in compliance by approximately January 2006. The Dam Bureau granted the 2-year extension to allow completion of this Phase I feasibility study and potentially a Phase II study. If dam removal does not occur then Pennichuck Water Works or another entity interested in purchasing the dam would likely request a budgetary estimate to resolve the deficiencies. A licensed Professional Engineer in New Hampshire should conduct a site inspection of the dam to render an opinion on dam stability, operation and maintenance costs and develop budgetary estimates to resolve the issues raised in the LOD.

### Historic/Archeological Studies

If dam removal were to proceed to Phase II, historical and archeological investigations would be required. As noted earlier in this report, consultation with the New Hampshire Division of Historic Resources (DHR) is required for dam removal projects. The DHR will require at a minimum that a Phase I assessment of Historic, Architectural and Engineering Resources be conducted. A qualified historian would complete a Project Area Form for submittal to DHR. DHR will also require that a Phase IA Reconnaissance Level archeological evaluation be conducted. A qualified archeologist would complete or update the DHR Archeological Inventory Forms.

### Ice Evaluation

As noted earlier in this report, if MVD is removed the potential for ice jamming near Chamberlain Bridge should be evaluated further. It is recommended that the Army Corps of Engineers Cold Regions Research and Engineering Laboratory be consulted with respect to potential icing issues and to determine if any additional analyses are needed.

### Deed and Title Search of the Dam Property

Typically, deed and title searches of the dam site and abutting properties are conducted. Our investigation was limited to the current PWW deed.

### Alternatives Analysis- Dam

This report considered one alternative for dam removal- full removal of the dam and apron. Typically, environmental advocates prefer full removal with the goal of allowing free upstream and downstream movement of fish and aquatic resources and full site restoration. PWW also prefers full removal to eliminate any further liability and costs associated with the dam. Other alternatives not considered include partial removal (lowering the spillway height), or removing a section of the dam in its entirety. These, and other potential alternatives, have not been carefully examined. For those alternatives that are practicable, preliminary cost estimates and conceptual drawings could be prepared.

### Alternatives Analysis- Wetlands

As noted in the wetlands section, the major wetland complex is located behind the fire department. If the dam is fully removed, and the sediment near the outlet of the wetland complex is also removed (mechanically or naturally), the wetland will become dewatered. The bottom of the sediment near the wetland outlet is well below the lowest depth of the wetland. Although it is likely that the wetland was created as a result of the dam, there will likely be concerns regarding the potential loss of the wetland. Therefore, alternatives for retaining a portion or all of the wetland should be explored. This report considered one very conceptual alternative, but other alternatives could be evaluated in consultation with the New Hampshire Wetlands Bureau, local conservation groups and others. For those alternatives that are practicable, further engineering and environmental studies should be conducted, as necessary.

In addition, consultation with the NH Natural Heritage Bureau may be necessary to evaluate the likelihood of rare, threatened or endangered species being impacted by dam removal.

#### Phase II Feasibility Study

Findings from the alternatives analyses, archeological/historic evaluations and other evaluations would be summarized in a Phase II Feasibility Study Report. If dam removal were to move forward with a preferred alternative the following plans and additional steps would be required:

- Water routing and management plan
- Detailed sediment management plan
- Dam removal strategy
- Staging and access plan
- Demolition debris handling and disposal plan
- Preparation of preliminary engineering design plans adequate for permitting purposes
- Preparation of all necessary federal, state and local regulatory approvals (permits)
- Preparation of final engineering design plans and specifications for construction purposes
- Preparation of project cost estimate for construction and construction oversight
- Preparation of bid documents for construction firms

#### Funding Sources for Dam Removal

If dam removal proceeds, several grant opportunities should be pursued relative to funding some of the dam removal effort. A potential list of contributors could include: USFWS, NHFG, the FishAmerican Foundation, American Rivers, Trout Unlimited, American Whitewater Association, NOAA, and others. These parties have contributed to other dam removal projects within NH. In addition, it may be possible to seek in-kind services for other features of the project. For example, the NHDES Dam Bureau Construction Crew has removed several dams in NH at a lower rate.

#### Public Outreach

It is suggested that additional public outreach be conducted in any future phases of this project. This would include additional meetings, as needed, throughout the process.

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